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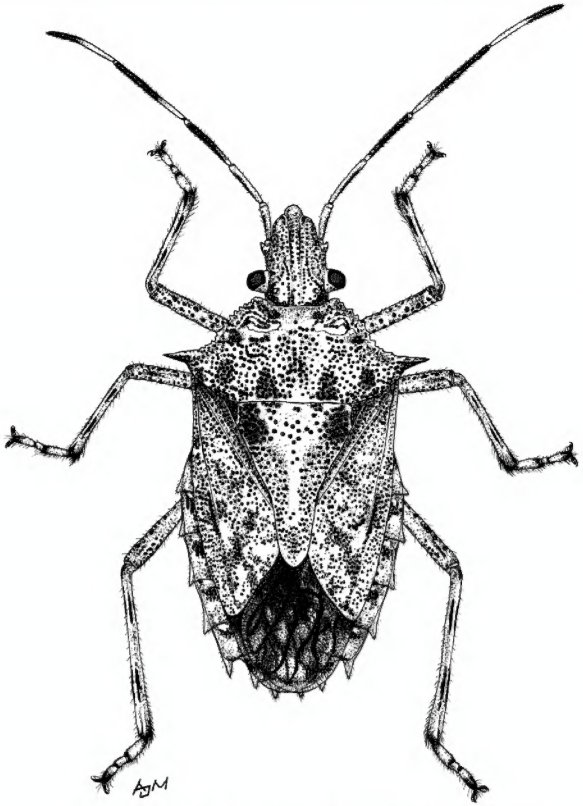

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COVER

Bromocoris souefi (Distant, 1910) (Hemiptera: Pentatomidae) was described by British hemipterist, W.L. Distant, from a specimen collected at Cooktown in 1896 by W.H.D. Le Souëf after whom it is named. He was son of the Director of the Melbourne Zoo and collected it on an expedition to collect tree kangaroos for the zoo. It occurs in Indonesia, New Guinea and northern Australia. Its range in Australia has recently expanded southerly and it has been common in Brisbane since 2006. Females brood and vigorously guard their eggs and first instars on the undersides of leaves of many tree species. The illustration is ink on paper by ESQ member Dr Andrew Maynard who received his UQ PhD in 2020 on the invasion history and evolution of *Aedes albopictus* and *Aedes aegypti* in the Indo-Pacific. He works in Brisbane at the Dept. of Agriculture, Water and the Environment as a biosecurity entomologist with special interest in Hemiptera. *Bromocoris souefi* is routinely intercepted.

A REVISION OF THE ENDEMIC AUSTRALIAN CICADA GENUS *JASSOPSALTRIA* ASHTON, 1914 (CICADIDAE: CICADINAE: JASSOPSALTRIINI)

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Abstract

The single described species of *Jassopsaltria*, *J. rufifacies* Ashton is re-described, four new species of *Jassopsaltria* Ashton are described from Western Australia (*J. aeroides* **sp. n.**, *J. cinnamomea* **sp. n.**, *J. minilyaensis* **sp. n.**, *J. gracilens* **sp. n.**) and one new species is described from the Northern Territory (*J. danielsorum* **sp. n.**). A key is provided to the six known species, and the male calling songs of all Western Australian species are presented.

Keywords: Cicadoidea, cicada songs, Western Australia, Northern Territory

Introduction

The genus *Jassopsaltria* Ashton, 1914 was established by Ashton to accommodate just one species, *J. rufifacies* Ashton, 1914. He did not allocate the genus to a tribe or subfamily, even though Distant (1906) had previously established a higher classification for the Cicadidae. Metcalf (1963) placed *Jassopsaltria* in the tribe Parnisini Distant, subfamily Tibicininae (now Cicadettinae), apparently from Ashton's description and without seeing a specimen. This classification was followed by Burns (1957), Duffels and van der Laan (1985) and Moulds (1990). Moulds (2005) erected the tribe Jassopsaltriini and simultaneously transferred it from the subfamily Cicadettinae to the subfamily Cicadinae, a change later supported by the molecular study of Marshall *et al.* (2018). The original misplacement by Metcalf was no doubt due to Ashton's statement that the genus lacked timbal covers, but *Jassopsaltria* does have timbal covers although much reduced (Moulds 2005, 2012).

We here describe an additional five species of *Jassopsaltria* (Figs 1–12), four from Western Australia and one from the Northern Territory, although the latter's known distribution lies very close to the Western Australian border. While additional collecting may clarify distributions further, all six species appear to have small distributions with four at least qualifying as narrow range endemics. Three species, *J. aeroides* sp. n., *J. danielsorum* sp. n. and *J. minilyaensis* sp. n., are only known from very small areas (Figs 19, 20). *Jassopsaltria gracilens* sp. n. has by far the widest distribution of the six species, with populations at either end of the Great Sandy Desert from the Western Australian coast to Wolfe Creek Meteorite Crater near the Northern Territory border (Fig. 20).

A key is provided to all six species and the songs of the five Western Australian species are described.

The following abbreviations are used for collections housing specimens: **AM**, Australian Museum, Sydney; **ANIC**, Australian National Insect Collection, Canberra; **DE,** collection of David Emery; **KG**, collection of Kees Green; **LP**, collection of Lindsay Popple; **MSM**, first author's collection; **PMH**, collection of Paul M. Hutchinson; **SAM**, South Australian Museum, Adelaide; **WAM**, Western Australian Museum, Perth. Specimens listed in the material examined sections with voucher codes given from the C. Simon laboratory, University of Connecticut (**UCONN**), may have one or more legs stored separately in ethanol for DNA preservation at that institution.

Terminology for morphological features follows that of Moulds (2005, 2012). Terminology for male calling song descriptions is as follows: A *pulse* is a burst of sound energy containing multiple sound *waves* (waves are the primary pressure-amplitude oscillation, which dampens to zero if not followed by another sound burst). This definition does not assume a specific mechanism, so a pulse could be created by one timbal collapsing or rebounding, both timbals collapsing/rebounding in synchrony, or one or more ribs of one or both timbals collapsing/rebounding (e.g. Fleming, 1975). A *syllable* is a group of pulses repeated at an approximately uniform rate. A *macrosyllable* is a group of repeated syllables.

Measurements of acoustic features were made in Raven version 1.5 Pro (Cornell Lab of Ornithology, Ithaca, NY). Repetition rates of sound components were measured from oscillograms (waveforms) to the nearest 0.001 s and are presented here as ranges of observed values. Recordings were filtered to remove sound energy below about 8 kHz. Sound pitch/frequency measurements were made from power spectra generated with the following parameter settings: Hann window, window size 256 samples, 23 decibels (dB) filter bandwidth 270 Hz, DFT size 256 samples, grid spacing 188 Hz, overlap 50%, hop size 128 samples, averaging 1 spectrum, with no clipping. The peak frequency of a song or song segment was identified as the sound pitch at which maximum sound amplitude was observed over a time segment of 1 s in duration, and the main song frequency band was delimited by the frequency values above and below the peak frequency at which sound intensity first dropped by more than 10 dB. Air temperatures were recorded with an Omega HH-25KF temperature meter and type K thermocouple (OMEGA Engineering, Stamford, CT), or in some cases with an ordinary household digital thermometer. Voucher or example recordings for each species will be deposited at the online repository BioAcoustica (http://bio.acousti.ca).

Key to species of *Jassopsaltria*

1. Rostrum reaching to bases of hind coxae 2
– Rostrum extending much further than bases of hind coxae 3

2. Forewing less than 14 mm long; dark reddish brown cicadas ..... ***J. danielsorum* sp. n.**
– Forewing more than 15 mm long; light to mid brown cicadas, never reddish brown ..... ***J. gracilens* sp. n.**

3. Postclypeus reddish brown or dark brown 4
_ Postclypeus pale, either with or without narrow black lateral grooves 5

4. Postclypeus reddish brown; in life body light green or rarely red ..... ***J. rufifacies*** Ashton
_ Postclypeus dark brown; in life body light to mid brown ..... ***J. cinnamomea* sp. n.**

5. Postclypeus entirely lacking markings ..... ***J. aeroides* sp. n.**
Postclypeus with black lateral grooves .....***J. minilyaensis* sp. n.**

Jassopsaltria rufifacies Ashton
(Figs 2, 7, 13, 19)

Jassopsaltria rufifacies Ashton, 1914: 350, pl. 17, figs 4, 4a, 4b.

Material examined. WESTERN AUSTRALIA: *Holotype* ♂, bearing three labels (1) Cue WA/ H.W. Brown (printed); (2) Type (on red circle); (3) Jassopsaltria rufifacies Asht./ TYPE; examined (the type locality is doubtful, see comment below under 'Distribution and habitat') (in SAM). *Other material*: 2 ♂♂, Star Swamp, nr Perth, 31°51.20's, 115°45.50'E, 8.ii.2015, K. Green (KG). 1 ♂, AU.WA.KBB, 34 km SE of Kalbarri, 244 m, 27°53.021'S 114°31.511'E, 20.ii.2009, K. Hill & D. Marshall; 3 ♂♂ (2 Simon Lab. vouchers 10.AU.WA.GRE.01, 10.AU.WA.GRE.02), ~9 km SE of Greenough, 12 m, 29°00.864'S 114°46.956'E, 14.i.2010, Hill, Marshall. Moulds; 1 ♀, Geraldton, 10.v.1984, K. & E. Carnaby; 6 ♂♂ (2 Simon Lab. vouchers 03.AU.WA.CAT.02, 03.AU.WA.CAT.10), Cataby, 144 m, 30°44'S 115°33'E, 19.i.2003, Moulds, Marshall, Hill & Vanderpool; 2 ♂♂, AU.WA.MOX, ~4 km NW of Wongan Hills, 350 m, 30°51.545'S 116°41.374'E, 13.i.2010, Hill, Marshall, Moulds; 4 ♂♂ (1 genitalia prep. J1), 1 ♀, Woodridge, 11.ii.1985, K. & E. Carnaby (MSM). 21 specimens Chapman River, Geraldton, 7.i.1966 (Natural History Museum, London). 1 ♂, AU.WA.CAT, Cataby, 144 m, 30°44'S 115°33'E, 19.i.2003, Moulds, Marshall, Hill & Vanderpool (UCONN). 2 ♂♂, AU.WA.CAT, Cataby, 144 m, 30°44'S 115°33'E, 19.i.2003, Moulds, Marshall, Hill & Vanderpool (WAM).

Distribution and habitat (Fig. 19)

Coastal and subcoastal districts of Western Australia between Kalbarri and Perth. The most northern locality is 34 km SE of Kalbarri and the most southern record is Star Swamp, Perth. The most inland confirmed record is Wongan Hills some 100 km NNE of Perth. The type locality is Cue but this falls far beyond the confirmed habitat for this species and the locality is here considered erroneous. The type was collected by H.W. Brown who is known for other questionable records (e.g. the type locality of *Froggattoides typicus* Distant (Moulds 1990, 2012)). Adults have been taken in January, February and May.

Adults inhabit low shrubland (often growing on white sand), where they are usually found on *Acacia spathulifolia* Maslin upon which the species breeds (Moulds 1990). The yellowish green colour of this *Acacia* provides excellent camouflage for the similarly coloured adults.

Adult morphology (Figs 2, 7, 13)
In life light green with pale orange markings; rarely in a red form. Dried collection specimens often light yellowish brown. The single known red specimen is uniformly coloured orange red without markings. We describe here only the usual green form.

Male (Figs 2, 7, 13). *Head*. Light green, sometimes with a little brown near ocelli; postclypeus and anteclypeus dark reddish brown; lorum green with shades of grey distally and a narrow black edge against lower postclypeus and upper anteclypeus; rostrum long, extending much further than bases of hind coxae, pale green becoming black distally. Eyes of live specimens light brown. *Thorax* light green, with pale orange markings. Pronotum sometimes with pale orange in fissures and along anterior margin between bases of fissures. Mesonotum with a broad band of pale orange either side and hints of pale orange on submedian sigilla; rarely with a narrow dark reddish-brown fascia near wing groove; in fresh specimens a line of silver pubescence along upper margin of wing groove reaching cruciform elevation. *Wings* hyaline. Forewing venation tending blue in vicinity of clavus, otherwise green on a little more than basal half except for basal portion of M and CuA tending pale orange, distally venation black; basal cell translucent bluish; basal membrane pale greenish grey. Hindwing venation very pale tending translucent. *Legs* with coxae, trochanters and femora green but darkest on coxae, foretibiae and tarsi brown, midtibiae pale orange at proximal end thereafter bluish becoming brown distally, mid- and hindtarsi brown. Meracantha greenish. *Opercula* pale green; in life usually covered in silver pubescence. *Timbal covers* small, tending triangular, reaching less than halfway across timbal cavity and substantially reduced along upper margin; timbals with five long ribs spanning timbal membrane, ribs 1 and 2 (the two longest) joined dorsally. *Abdomen* with tergites green tending blue on tergite 8; sternites I–VI pale orange, sternites VII–VIII green, in life sternites I–VII usually with silver pubescence along lateral margins.

Genitalia (Fig. 13). Pygofer basal lobe lying tight against upper lobe, broad and apically rounded in lateral view, long and slender in ventral view; distal shoulders acutely pointed, distally directed; dorsal beak absent. Uncus long and slender, a little wider on its distal half in dorsal view, apically rounded, concave below. Aedeagus broadly curved through 180° at about mid length so that the distal half is almost parallel with much of proximal half, expanded distally on underside with the expansion gradually reducing towards apex.

Female. Similar to male. Abdominal segment 9 green, the same as body. Ovipositor sheath green, barely protruding beyond anal styles.

Measurements

Range and mean (in mm) for 10 males, 2 females (includes smallest and largest specimens). *Length of body* (including head): male 11.0–14.5 (13.5); female (including ovipositor) 14.6–14.6 (14.6). *Length of forewing*: male 12.8–15.9

Figs 1–6. *Jassopsaltria* species, live in natural habitat: (1) *J. minilyaensis* sp. n.; (2) *J. rufifacies*; (3) *J. gracilens* sp. n., mating pair, female uppermost; (4) *J. aeroides* sp. n.; (5) *J. cinnamomea* sp. n.; (6) *J. gracilens* sp. n., in song.

(15.2); female 16.6–17.0 (16.8). *Width of head* (including eyes): male 4.6–5.5 (5.2); female 5.8–5.9 (5.85). *Width of pronotum* (across lateral angles): male 4.7–5.7 (5.4); female 6.2–6.2 (6.2).

Distinguishing features

Differs from all other *Jassopsaltria* species in having, in combination, a rostrum that extends well beyond the bases of the hind coxae, and a postclypeus that is uniformly reddish brown. The male genitalia have a slender uncus that is slightly wider on its distal half in dorsal view, and an aedeagus that is expanded distally on underside, the expansion gradually reducing towards apex.

Jassopsaltria aeroides sp. n.

(Figs 4, 9, 14, 19)

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Types. *Holotype* ♂ (Simon Lab. voucher 09.AU.WA.OVM.01, song recorded) (WAM reg. No. E109775), Western Australia, 43 km N of Overlander Roadhouse, NW Coastal Hwy, 26°1.602'S 114°19.092'E, 15.i.2010, Hill, Marshall, Moulds (WAM). *Paratypes as follows*: WESTERN AUSTRALIA: 1 ♂, AU.WA.OVN, 31.9 km N of Overlander Roadhouse, 26°8.333'S 114°21.644'E, 12.ii.2009, K. Hill & D. Marshall (DE). 1 ♂, same data as previous (LP). 4 ♂♂ (1 genitalia prep. JAS5; 1 Simon Lab. voucher 09.AU.WA.OVN.02), 1 ♀, same data as previous; 4 ♂♂ (2 Simon Lab. vouchers 10.AU.WA.OVM.01, 10.AU.WA.OVM.02), 1 ♀, same data as holotype (MSM). 1 ♂, AU.WA.OVN, 31.9 km N of Overlander Roadhouse, 26°8.333'S 114°21.644'E, 12.ii.2009, K. Hill & D. Marshall (PMH). 3 ♂♂ (WAM reg. Nos E109776–109778), AU.WA.OVN, 31.9 km N of Overlander Roadhouse, 26°8.333'S 114°21.644'E, 12.ii.2009, K. Hill & D. Marshall; 2 ♂♂ (WAM reg. Nos E109779–109780), AU.WA.OVM, same data as holotype (WAM).

Etymology

From the Latin *aeroides* and referring to the blue colour of the eyes and wing veins of this species.

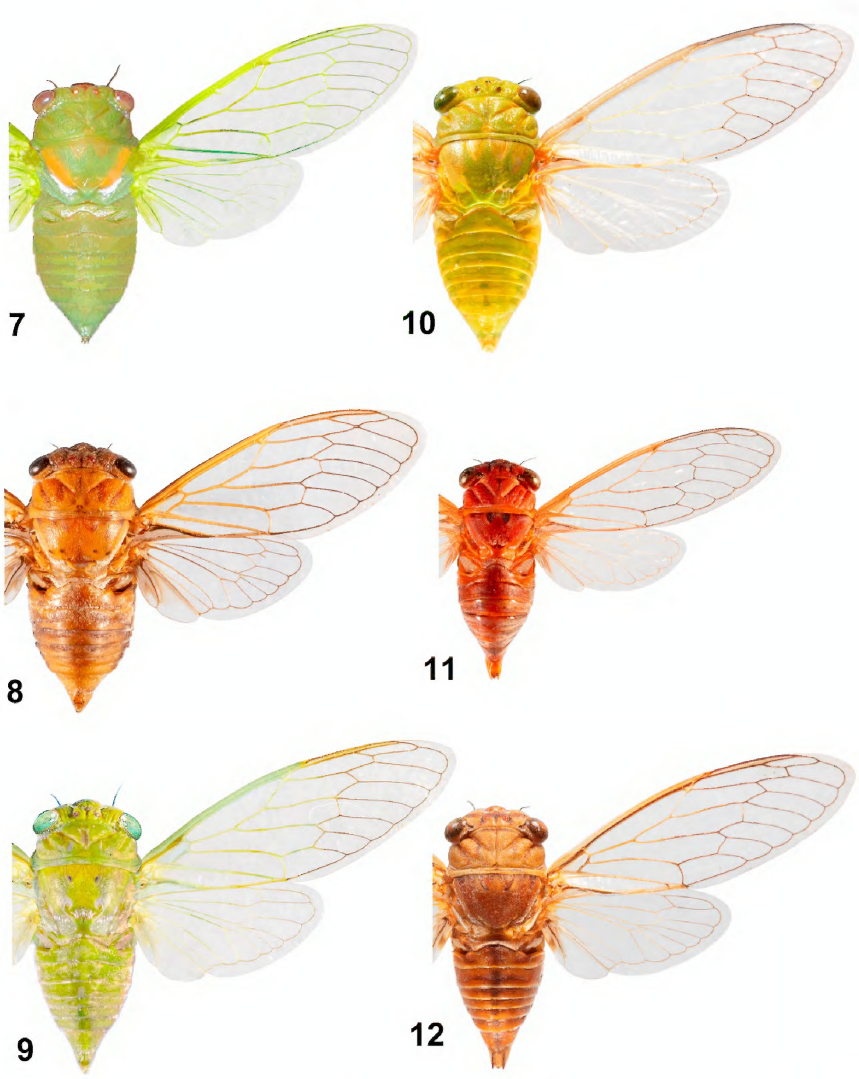
Distribution and habitat (Fig. 19)

Known from just two localities in the far west of Western Australia, 32 km and 43 km north of the Overlander Roadhouse (near Shark Bay). There are records for mid January and mid February only. Adults inhabit *Acacia* bushes in semi-arid open shrubland.

Adult morphology (Figs 4, 9, 14)

In life light green with a blue tinge and few markings. Dried collection specimens often light yellowish brown.

Male (Figs 4, 9, 14). *Head* light green; postclypeus and anteclypeus pale brown with a broad medial area; lorum green with shades of pale brown distally; rostrum long, extending much further than bases of hind coxae, pale brown basally becoming black distally. Eyes of live specimens bluish. *Thorax* light green. Pronotum with fissures pale brown and along anterior margin between bases of fissures. Mesonotum sometimes with submedian sigilla a little darkened with



Figs 7–12. *Jassopsaltria* species, dorsal: (7) *J. rufifacies*; (8) *J. cinnamomea* sp. n.; (9) *J. aeroides* sp. n.; (10) *J. minilyaensis* sp. n.; (11) *J. danielsorum* sp. n.; (12) *J. gracilens* sp. n. Approximately 3x natural size.

brown, occasionally black at apex; in fresh specimens a line of silver pubescence along upper margin of wing groove reaching cruciform elevation. *Wings* hyaline. Forewing venation bluish becoming black on distal half; basal cell translucent bluish; basal membrane pale bluish grey. Hindwing venation very pale tending

translucent on basal half or more, becoming black distally. *Legs* with coxae, trochanters and femora green, foretibiae and tarsi brown, midtibiae pale orange at proximal end thereafter bluish becoming brown distally, mid- and hindtarsi brown. Meracantha greenish. *Opercula* very pale green; in life usually covered in silver pubescence. *Timbal covers* greatly reduced to not much more than a narrow ridge that is partly sloping forwards; timbals with five long ribs spanning timbal membrane, ribs 1 and 2 (the two longest) joined dorsally. *Abdomen* with tergites green tending blue on tergite 8; sternites I–VI pale orange, sternites VII–VIII green, in life sternites I–VII usually with silver pubescence along lateral margins.

Genitalia (Fig. 14). Pygofer basal lobe lying tight against upper lobe, broad and apically rounded in lateral view, long and slender in ventral view; distal shoulders acutely pointed, distally directed; dorsal beak absent. Uncus widest a little before mid length, apically rounded, concave below. Aedeagus slender, tubular, broadly curved through almost 180° at about mid length so that the distal half is almost parallel with much of proximal half, slightly swollen distally, the apex in lateral view slightly sloping backwards.

Female. Similar to male. Abdominal segment 9 green, the same as body. Ovipositor sheath green, barely protruding beyond anal styles.

Measurements

Range and mean (in mm) for 10 males, 2 females (includes smallest and largest specimens). *Length of body* (including head): male 12.6–14.3 (13.3); female (including ovipositor) 11.5–13.3 (12.4). *Length of forewing*: male 17.0–18.3 (17.5); female 16.7–18.3 (17.5). *Width of head* (including eyes): male 5.4–5.9 (5.6); female 5.3–5.8 (5.55. *Width of pronotum* (across lateral angles): male 5.4–6.0 (5.6); female 5.4–6.0 (5.6).

Distinguishing features

Differs from all other *Jassopsaltria* species in having the postclypeus uniformly pale and entirely without markings. The rostrum extends far beyond the base of hind coxae and in life adults are pale blue in colour. The male genitalia have a slender uncus that is widest a little before mid length in dorsal view.

Jassopsaltria danielsorum sp. n.

(Figs 11, 16, 19)

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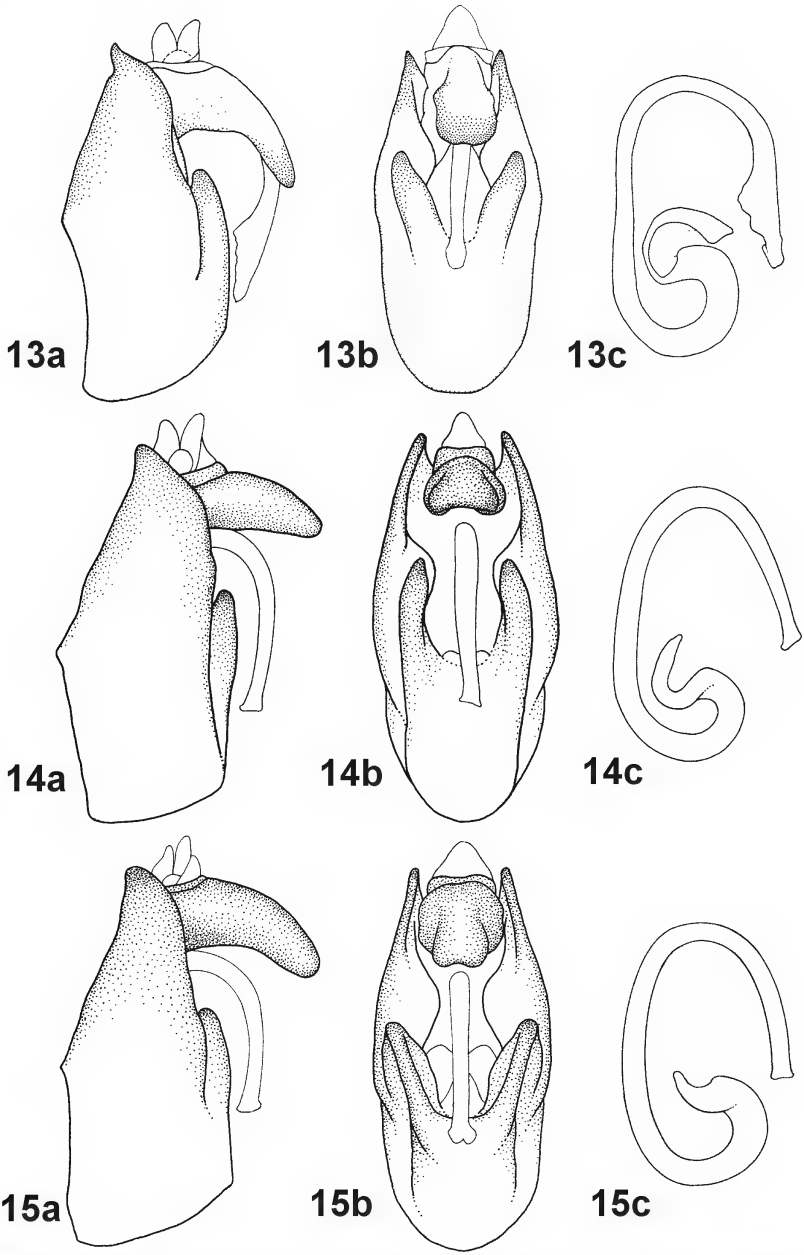
Types. *Holotype* ♂ (WAM reg. No. E109817), Northern Territory, Gurrandalng [= Goorrandalng] camping area, Keep River Nat. Park, 100 m, 15°52'S 129°03'E, 3.i.1993, G. & A. Daniels (WAM). *Paratypes as follows*: NORTHERN TERRITORY: 2 ♂♂ (1 genitalia prep. JAS 4), 2 ♀♀, same data as holotype (MSM).

Etymology

Named for Greg and Alice Daniels who collected the type series and who have contributed enormously to Australian entomology through their extensive collecting spanning more than 50 years.



Figs 13–15. Male genitalia of *Jassopsaltria* species, (a) lateral view, (b) ventral view and (c) aedeagus: (13) *J. rufifacies*; (14) *J. aeroides* sp. n.; (15) *J. cinnamomea* sp. n.

Distribution and habitat (Fig. 19)
Known only from the upper reaches of the Keep River, Northern Territory, where the only recorded specimens were taken in early January. Adults were found in an area of scattered eucalypts with a ground cover of mostly spinifex (*Triodia* sp.) (G. Daniels, pers. comm.).

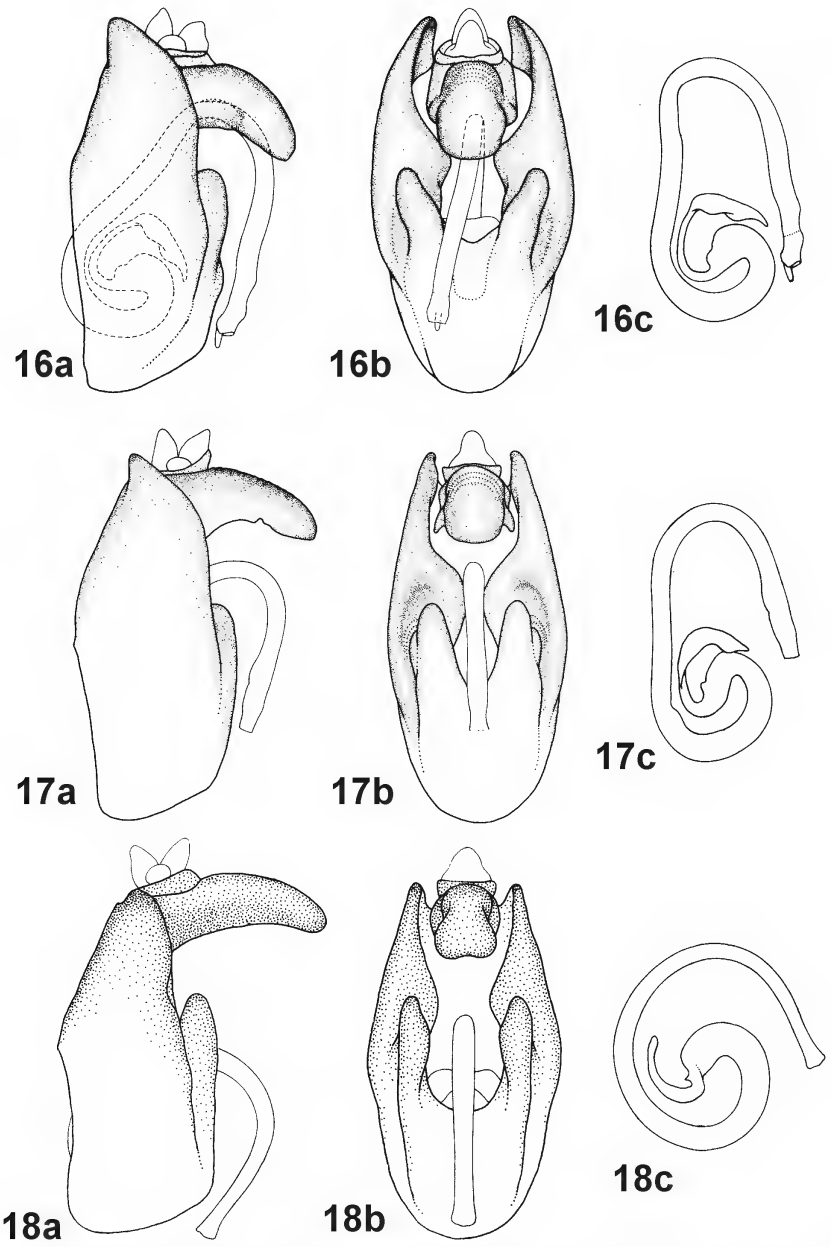
Adult morphology (Figs 11, 16)
Male (Figs 11, 16). *Head* reddish brown with a little black edging the ocelli, along furrows between lateral ocelli and postclypeus and as a small spot near back of eyes, all variable; supra-antennal plates orange brown; postclypeus glossy brown to reddish brown; anteclypeus black with a broad dark brown midline; lorum black; rostrum reaching to bases of hind coxae, light brown becoming black distally. *Thorax* reddish brown, with a few black markings. Pronotum tending black along midline, along fissures and along anterior margin between bases of fissures. Mesonotum with submedian sigilla partly or entirely black and sometimes a little black at bases of lateral sigilla; scutal depressions brown or black. *Wings* hyaline. Forewing with vein 3A black, otherwise venation brown becoming black at apical cells; basal cell translucent light brown; basal membrane grey. Hindwing venation pale brown tending translucent through medial area. *Legs* light brown to reddish brown. Meracantha pale yellowish brown with blackish base. *Opercula* very pale brown suffused black along inner margin to apex; in life usually covered in silver pubescence. *Timbal covers* greatly reduced to not much more than a narrow ridge that is partly sloping forwards; timbals with five long ribs spanning timbal membrane, ribs 1 and 2 (the two longest) joined dorsally. *Abdomen* with tergites reddish brown; sternites brown with medial part of sternite II black; in life sternites I–VII usually with silver pubescence along lateral margins.

Genitalia (Fig. 16). Pygofer basal lobe lying tight against upper lobe, broad and apically rounded in lateral view, long and slender in ventral view; distal shoulders acutely pointed, distally directed; dorsal beak absent. Uncus slender, parallel-sided in dorsal view, apically broadly rounded, concave below. Aedeagus slender, tubular without taper, turned through approximately 180° basally and at about mid length so that distal half is tending parallel with much of proximal half, the apex square-cut.

Female. Similar to male. Abdominal segment 9 light brown, darker on dorsal surface and upper half of lateral anterior margin, black along ventral margin and lower half of lateral anterior margin, the dorsal beak dark brown. Ovipositor sheath dark brown, extending no further than anal styles.

Measurements

Range with mean (in mm) for 3 males, 2 females (includes all available specimens). *Length of body* (including head): male 9.9–10.9 (10.3); female (including ovipositor) 10.1–10.3 (10.2). *Length of forewing*: male 13.3–13.9 (13.5); female 14.5–14.7 (14.6). *Width of head* (including eyes): male 3.9–4.2



Figs 16–18. Male genitalia of *Jassopsaltria* species, (a) lateral view, (b) ventral view and (c) aedeagus: (16) *J. danielsorum* sp. n.; (17) *J. gracilens* sp. n.; (18) *J. minilyaensis* sp. n.

(4.1); female 4.0–4.2 (4.1). *Width of pronotum* (across lateral angles): male 3.8–4.1 (4.0); female 3.9–4.1 (4.0).

Distinguishing features

Distinguished from all other *Jassopsaltria* species in having, in combination, a rostrum that reaches to bases of hind coxae (rather than far beyond), and a forewing length *less than* 14 mm. In life they are dark reddish cicadas. The male genitalia have a slender uncus that is parallel-sided in dorsal view, and an aedeagus that has the apex square-cut.

***Jassopsaltria cinnamomea* sp. n.**

(Figs 5, 8, 15, 20)

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Types. *Holotype* ♂ (Simon Lab. voucher 03.AU.WA.EEE.01) (WAM reg. No. E109781), Western Australia, 16 km E of Eneabba, 29°45.392'S 115°24.789'E, 237 m, 21.i.2003, Moulds, Hill, Marshall, Vanderpool (WAM). *Paratypes as follows*: WESTERN AUSTRALIA: 1 ♂, same data as holotype (DE). 1 ♂, same data as holotype (LP); 3 ♂♂ (1 genitalia prep. JAS7), Red Bluff, near coast N of Geraldton, 26.ix.1971, N. McFarland; 7 ♂♂, 2 ♀♀, Red Bluff, Kalbarri, 22.ix.1978, M.S. & B.J. Moulds; 5 ♂♂, 1 ♀, Hawatharra Hill Reserve, 30 km NNE of Geraldton, 28°33'S 114°40'E, 7.xii.1973, 23.i.1974, N. McFarland; 7 ♂♂ (1 genitalia prep. JAS1); 1 ♀, same data as holotype (MSM). 1 ♂, Red Bluff, Kalbarri, 22.ix.1978, M.S. & B.J. Moulds (PMH). 6 ♂♂ (WAM reg. Nos E109782–E109787), 1 female (WAM reg. No. E109788), same data as holotype (WAM).

Etymology

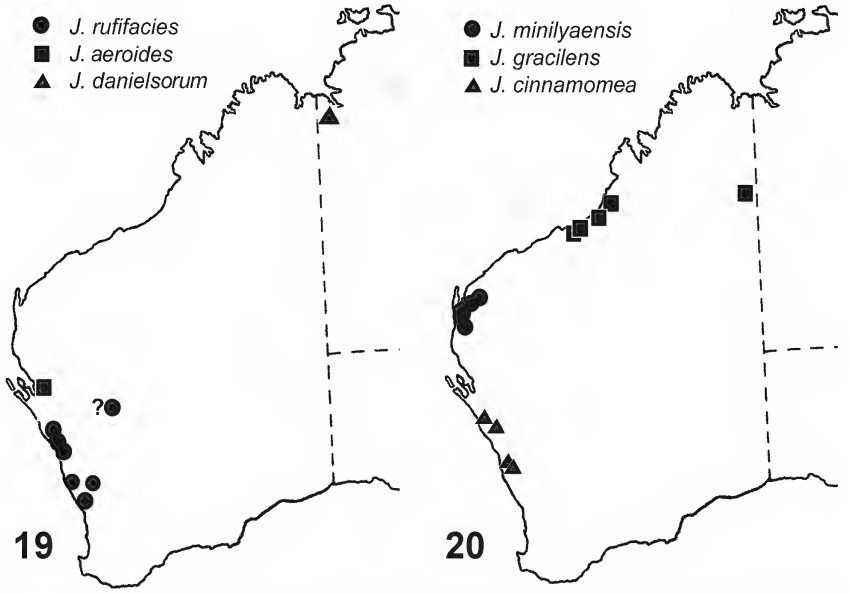
From the Latin *cinnamum* and referring to the cinnamon-like colour of this species.

Distribution and habitat (Fig. 20)

Subcoastal districts of Western Australia between Kalbarri and Eneabba. There are only three known localities, Red Bluff near Kalbarri, Hawatharra Hill Reserve near Geraldton, and 16 km east of Eneabba. There are records from late November to late January. Adults inhabit shrubs in open shrubland and are probably associated with *Acacia*.

Adult morphology (Figs 5, 8, 15)

Male (Figs 5, 8, 15). *Head* dark brown, sometimes a little paler near eyes; supra-antennal plates dark brown; postclypeus dark brown with a broad slightly paler midline; anteclypeus and lorum dark brown; rostrum long, extending much further than bases of hind coxae, mid brown basally becoming black distally. *Thorax* light to mid brown, with few darker markings. Pronotum tending dark brown along midline and fissures, and usually with a black patch on anterior of lateral angles that rarely extends to eye. Mesonotum with submedian and lateral sigilla partly or entirely dark brown; scutal depressions dark brown or black; cruciform elevation sometimes dark brown at anterior and posterior margin; in fresh specimens a line of silver pubescence along upper margin of wing groove reaching cruciform elevation. *Wings* hyaline. Forewing with vein 3A black,



Figs 19, 20. Distribution of *Jassopsaltria* species: (19) *J. rufifacies*, *J. aeroides* sp. n. and *J. danielsorum* sp. n.; (20) *J. minilyaensis* sp. n., *J. gracilens* sp. n. and *J. cinnamomea* sp. n.

otherwise venation brown becoming darker at apical cells; basal cell translucent, in part lightly tinted brown; basal membrane pale brown. Hindwing venation brown, the anal lobe tinted brown on basal half to three quarters. *Legs* brown, but yellowish at the joint between mid and hind femur and tibia. Meracantha brown tending yellowish towards apex. *Opercula* pale yellowish to light brown on basal half, black on distal half. *Timbal covers* greatly reduced to not much more than a narrow ridge that is partly sloping forwards; timbals with five long ribs spanning timbal membrane, ribs 1 and 2 (the two longest) joined dorsally. *Abdomen* with tergites mid to dark brown, suffused black sublaterally, the epipleurites pale yellowish to mid brown; sternites pale yellowish to mid brown; sternite II a mixture of mid and dark brown with auditory capsule dark brown to blackish; sternite VIII with midline partly suffused dark brown.

Genitalia (Fig. 15). Pygofer basal lobe lying tight against upper lobe, broad and apically rounded in lateral view, long and slender in ventral view; distal shoulders bluntly pointed, distally directed; dorsal beak absent. Uncus slender, almost parallel-sided in dorsal view but a little swollen on distal half or less, apically broadly rounded, concave below. Aedeagus gradually tapering throughout its length becoming slender distally, tubular, broadly curved through almost 180° at about mid length so that the distal half is almost parallel with much of proximal half, the apex a little expanded with a gently sloping end.

Female. Similar to male. Abdominal segment 9 light brown, darker on basal half or so, the dorsal beak dark brown. Ovipositor sheath brown, extending no further than anal styles.

Measurements

Range and mean (in mm) for 10 males, 4 females (includes smallest and largest specimens). *Length of body* (including head): male 10.7–13.5 (12.4); female (including ovipositor) 11.6–12.9 (12.1). *Length of forewing*: male 13.8–15.7 (14.8); female 14.0–14.8 (14.5). *Width of head* (including eyes): male 4.9–5.6 (5.2); female 4.9–5.4 (5.2). *Width of pronotum* (across lateral angles): male 5.0–5.9 (5.5); female 5.6–5.7 (5.65).

Distinguishing features

Differs from all other *Jassopsaltria* species in having, in combination, a rostrum that extends much further than the base of hind coxae, and a dark brown postclypeus. In life they are brown cicadas with slightly darker brown eyes. The male genitalia have a slender uncus slightly swollen on its distal half or less, and an aedeagus that has the apex a little expanded with a gently sloping end.

Jassopsaltria gracilens sp. n.

(Figs 3, 6, 12, 17, 20)

urn:lsid:zoobank.org:act:55BB8D72-7E2D-46DC-8726-E82C0959DBDB

Types. *Holotype* ♂ (Simon Lab. voucher 06.AU.WA.NSR.02, song recorded) (WAM reg. No. E109789), Western Australia, 23 km NE of Sandfire Rdhouse, 16 m, 19°40.741'S 121°16.042'E, 9.ii.2006, Hill, Marshall, Moulds (WAM). [GPS values from 2006 were taken using the map datum Geodetic Datum 49.] *Paratypes as follows*: WESTERN AUSTRALIA: 1 ♂, 1 ♀, near Wolfe Creek Meteorite Crater, 19°10.908'S 127°46.636'E, 25-26.i.2010, Hill Marshall Moulds (DE). 10 ♂♂, 1 ♀, Wolfe Creek, WA, 19°11'S 127°46'E, 19.x.2009, L.W. Popple; 1 ♂, 1 ♀, near Wolfe Creek Meteorite Crater, 19°10.908'S 127°46.636'E, 25,26.i.2010, Hill Marshall Moulds (LP). 3 ♂♂, 06.AU. WA.NSR same data as holotype; 12 ♂♂ (1 Simon Lab. voucher 06.AU.WA.EPR.01), 1 ♀, 180 km NE of Port Hedland, 11 m, 19°59.298'S 120°04.919'E, 10.ii.2006, Hill, Marshall, Moulds; 1 ♂, AU.WA.WPR, 147 km ENE of Port Hedland, 14 m, 20°04.940'S 119°46.205'E, 10.ii.2006; Hill, Marshall, Moulds; 4 ♂♂, 160 km ENE of Port Hedland, 20°00'S 120°00'E, 9.ix.1978, M.S. & B.J. Moulds; 3 ♂♂ (1 genitalia prep. JAS 2), 2 ♀♀, 80 km N of Sandfire Flat, nr Nita Hsd, 29.xii.1985, M.S. & B.J. Moulds; 2 ♂♂, AU.WA. TMH, Tanami Rd, 13 km SE of Bililuna, 312 m, 19°37.796'S 127°44.431'E, 26.i.2010, Hill, Marshall, Moulds; 9 ♂♂ (1 genitalia prep. JAS 3), 4 ♀♀, near Wolfe Creek Meteorite Crater, 19°10.908'S 127°46.636'E, 25,26.i.2010, Hill Marshall Moulds; 1 ♂, AU.WA.SHN, 27 km N of Shay Gap, NNE of Marble Bar, 20°13.861'S 120°12.523'E, 18.i.2010, Hill, Marshall, Moulds (MSM). 1 ♂, near Wolfe Creek Meteorite Crater, 19°10.908'S 127°46.636'E, 25-26.i.2010, Hill Marshall Moulds (PMH). 1 male (Simon Lab. voucher 06.AU.WA.NSR.01), same data as holotype (UCONN). 1 male (WAM reg. No. E109790), AU.WA.WPR, 147 km ENE of Port Hedland, 14 m, 20°04.940'S 119°46.205'E, 10.ii.2006; Hill, Marshall, Moulds; 2 ♂♂ (WAM reg. Nos E109791–E109792), 80 km N of Sandfire Flat, nr Nita Hsd, 29.xii.1985, M.S. & B.J. Moulds; 5 ♂♂ (WAM reg. Nos E109793–E109797), AU.WA.EPR, 180 km NE of Port Hedland, 11 m,

19°59.298'S 120°04.919'E, 10.ii.2006, Hill, Marshall, Moulds; 8 ♂♂ (WAM reg. Nos E109798–E109805), 2 ♀♀ (WAM reg. Nos E109806–E109807), AU.WA.WOL, near Wolfe Creek Meteorite Crater, 19°10.908'S 127°46.636'E, 25,26.i.2010, Hill Marshall Moulds (WAM).

Etymology
From the Latin *gracilis* meaning slender, and referring to the slender body of this species, a feature shared only with *J. danielsorum*.

Distribution and habitat (Fig. 20)
Western margin of the Great Sandy Desert, Western Australia, mostly along the Great Northern Highway between 160 and 375 km ENE of Port Hedland, and at the eastern extremity of the same desert near the Northern Territory border within 60 km of Wolfe Creek Meteorite Crater. There are records from mid October to mid February. Adults inhabit semi arid shrublands with taller *Acacia* growing on red soils or sand.

Adult morphology (Figs 3, 6, 12, 17)
Male (Figs 3, 6, 12, 17). *Head* with vertex light to mid brown, sometimes tending yellowish on lateral vertex; a wavy black fascia (rarely dark brown) between eyes passing around median ocellus and a black spot against outer margin of lateral ocelli that is sometimes merged with the wavy black fascia; a small black spot at back of vertex touching or near eye; supra-antennal plates pale yellow; postclypeus glossy mid brown sometimes partly pale yellowish on dorsal surface and around most anterior part; lorum black; anteclypeus dark brown; rostrum reaching to bases of hind coxae, mid to dark brown basally becoming black distally. Eyes in life variable in colour from light brown to orange brown to pink. *Thorax* light to mid brown, with few darker markings, ventrally largely overlaid with white pubescence. Pronotum black or sometimes dark brown along midline and in midline and fissures, and as a short bar against anterior margin either side of midline; anterior of lateral angles of pronotal collar with a black patch that sometimes extends to eye. Mesonotum with submedian sigilla black along their outer margin but occasionally more extensively black; lateral sigilla usually with hints of dark brown, rarely with black; scutal depressions dark brown or black; usually a dark brown match anterior of scutal depressions; cruciform elevation black between anterior arms. *Wings* hyaline. Forewing venation usually pale brown to yellowish on basal half or so becoming black on distal half, rarely all black; basal cell translucent without pigmentation; basal membrane grey. Hindwing venation mostly pale brown to yellowish becoming black only about distal half of apical cells. *Legs* a mixture of light to mid brown, the distal ends of mid and hind femora nearly always light brown. Meracantha pale yellowish with nearly black base. *Opercula* pale yellowish with inner margin from near meracanthus and apex suffused black. *Timbal covers* greatly reduced to not much more than a narrow ridge that is partly sloping forwards; timbals with five long ribs spanning timbal membrane, ribs 1 and 2 (the two longest) joined dorsally. *Abdomen* with tergites mid brown, partly suffused with black variable between

individuals but usually along anterior margins of segments; sternites laterally pale yellowish to mid brown overlaid with white pubescence, broadly suffused black medially; sternite I dark brown; sternite VIII black medially.

Genitalia (Fig. 17). Pygofer basal lobe lying tight against upper lobe, broad and apically rounded in lateral view, long and slender in ventral view; distal shoulders bluntly pointed, distally directed; dorsal beak absent. Uncus slender, parallel-sided in dorsal view, apically broadly rounded, concave below. Aedeagus slender, turned through approximately 180° basally and at about midlength so that distal half is tending parallel with proximal half, tubular with almost no taper, the apex tending concave when viewed from above.

Female (Fig. 3). Similar to male. Abdominal segment 9 light brown, darker on dorsal surface and lateral anterior margin, the dorsal beak dark brown to black. Ovipositor sheath dark brown, extending no further than anal styles.

Measurements

Range and mean (in mm) for 10 males, 10 females (includes smallest and largest specimens). *Length of body* (including head): male 11.8–12.8 (12.3); female (including ovipositor) 10.9–12.4 (11.7). *Length of forewing*: male 14.9–16.3 (15.7); female 15.3–17.3 (16.3). *Width of head* (including eyes): male 4.7–5.3 (5.0); female 4.7–5.3 (5.1). *Width of pronotum* (across lateral angles): male 4.7–5.3 (5.1); female 4.8–5.6 (5.2).

Distinguishing features

Distinguished from all other *Jassopsaltria* species in having, in combination, a rostrum that reaches to bases of hind coxae (instead of far beyond), and a forewing length more than 15 mm. In life they are light brown cicadas. The male genitalia have a slender uncus that is parallel-sided in dorsal view, and an aedeagus that has the apex tending concave when viewed from above.

***Jassopsaltria minilyaensis* sp. n.**

(Figs 1, 10, 18, 20)

urn:lsid:zoobank.org:act:A8296EBD-32D4-41CE-AB46-32B8C5A3603F

Types. *Holotype* ♂ (Simon Lab. voucher AU.WA.MYS.05, song recorded) (WAM reg. No. E109808), Western Australia, 36 km S of Minilya Rdhse, 98 km N of Carnarvon, 24°8.171'S 114°2.878'E, 22 m, 13.ii.2009, K. Hill & D. Marshall (WAM). *Paratypes as follows*: WESTERN AUSTRALIA: 1 male 09.AU.WA.MYS, same data as holotype (DE). 1 male 09.AU.WA.MYS, same data as holotype (LP). 1 ♂, AU.WA.MYM, 140 km NNE of Minilya R., NW Coast Hwy, 22°53.329'S 114°48.907'E, 85 m, 16.i.2010, Hill, Marshall, Moulds; 2 ♂♂ (1 genitalia prep. JAS6), AU.WA.MYN, 39 km N of Minilya Rdhse, 41m, 23°33.38'S 114°14.073'E, 13.ii.2009, K. Hill & D. Marshall; 9 ♂♂ (1 Simon Lab. voucher 09.AU.WA.MYS.02), 1 ♀, same data as holotype; 3 ♂♂ (2 Simon Lab. vouchers 09.AU.WA.CPX.01, 09.AU.WA.CPX.02), 125 km N of Minilya Roadhouse, 22°57.343'S 114°40.028'E, 13.ii.2009, K. Hill & D. Marshall; 1 ♂, AU.WA.NAS, 26.7 km S of Nanutarra Roadhouse, 22 42.462'S 115 19.388'E, 13.ii.2009, K. Hill, D. Marshall (MSM). 1♀ 09.AU.WA.MYS, same data as holotype (PMH). 1 male (WAM reg. Nos

88/395 and also 38324), 27 km NE of Giralia Hs, 16.xii.1978, D. Knowles & M. Hanlon; 1 male (WAM reg. No. E109809), AU.WA.CPX, 125 km N of Minilya Roadhouse, 22°57.343'S 114°40.028'E, 79 m, 13.ii.2009, K. Hill & D. Marshall; 7 ♂♂ (WAM reg. Nos E109810–E109816), AU.WA.MYS., same data as holotype (WAM).

Etymology
Named from the locality near which all known specimens have been found.

Distribution and habitat (Fig. 20)
Known only from a small area extending from 36 km south to 140 km north of Minilya (around 125 km north of Carnarvon), Western Australia. There are records from mid December to mid February. Adults inhabit open shrubland growing on red sand dunes. They can be found in all kinds of *Acacia* shrubs and on other random small plants.

Adult morphology (Figs 1, 10, 18)
Male (Figs 1, 10, 18). *Head* light green, sometimes with a little brown edging ocelli, along furrows between lateral ocelli and postclypeus and as a small spot near back of eyes, all variable; postclypeus glossy light brown with brown or black midline and transverse grooves; anteclypeus dark brown with light brown centre; lorum dark brown; rostrum long, extending much further than bases of hind coxae, brown becoming black distally. Eyes of live specimens light to mid brown. *Thorax* green with hints of pale orange. Pronotum with fissures pale brown and along anterior margin between bases of fissures. Mesonotum sometimes with submedian sigilla a little darkened, tending brown with a pale orange margin; scutal depressions sometimes brown or black; in fresh specimens a line of silver pubescence along upper margin of wing groove reaching cruciform elevation. *Wings* hyaline. Forewing with vein 3A black, otherwise venation pale green becoming black at apical cells; basal cell hyaline; basal membrane pale grey. Hindwing venation very pale tending translucent on basal half or more, becoming black distally. *Legs* mostly light brownish yellow or green and some brown markings. Forelegs with coxae, trochanters and femora green partly with brown overtones, the femora with longitudinal brown markings sometimes extensive. Mid- and hindlegs with coxae, trochanters and femora brownish yellow, the femora each with two or three distinct longitudinal brown fascia; tibiae and tarsi brown. Meracantha very pale brown. *Opercula* very pale brown; in life usually covered in silver pubescence. *Timbal covers* small, tending triangular, reaching a little beyond halfway across timbal cavity and substantially reduced along upper margin; timbals with five long ribs spanning timbal membrane, ribs 1 and 2 (the two longest) joined dorsally. *Abdomen* with tergites green tending blue on tergite 8; sternites pale brown, in life sternites I–VII usually with silver pubescence along lateral margins.

Genitalia (Fig. 18). Pygofer basal lobe lying tight against upper lobe, broad and apically rounded in lateral view, long and slender in ventral view; distal shoulders bluntly pointed, distally directed; dorsal beak absent. Uncus slender, tending a little wider on distal half or more, apically broadly rounded, concave

below. Aedeagus slender, tubular, spiralled, very gently tapered throughout its length, the apex a little expanded with a nearly square-cut end.

Female. Similar to male. Abdominal segment 9 green, the same as body. Ovipositor sheath dark brown, extending no further than anal styles.

Measurements

Range and mean (in mm) for 10 males, 1 female (includes smallest and largest specimens). *Length of body* (including head): male 11.8–13.0 (12.5); female (including ovipositor) 12.7. *Length of forewing*: male 15.7–17.3 (16.4); female 17.4. *Width of head* (including eyes): male 5.0–5.4 (5.2); female 5.6. *Width of pronotum* (across lateral angles): male 5.3–5.9 (5.5); female 5.8.

Distinguishing features

Differs from all other *Jassopsaltria* species in having a pale postclypeus with clearly defined black lateral grooves. In life they are green cicadas and the rostrum extends much further than bases of hind coxae. The male genitalia have a slender uncus that is slightly wider on its distal half or more, and an aedeagus that is spiralled in shape and very different in that respect from all other *Jassopsaltria* species.

Song variation in *Jassopsaltria*

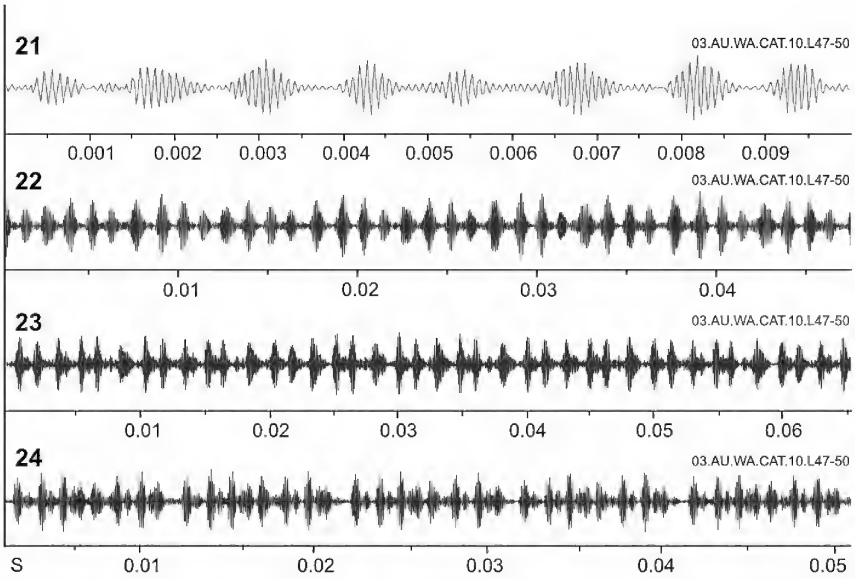
As most of the *Jassopsaltria* species have been audio recorded from only one or a few locations, and fine-scale structure is often variable within song samples as discussed below, the descriptions and conclusions on song structure and differences below should be viewed with this in mind. Additional recordings will likely expand the observed range of the song parameters measured.

Males of all species sing from low perches in vegetation and produce songs from a given position for at least many minutes at a time. They do not readily take to flight when carefully approached, and instead appear to rely on cryptic colouration for concealment. See the Types section for location details of specimen codes referenced below for each species.

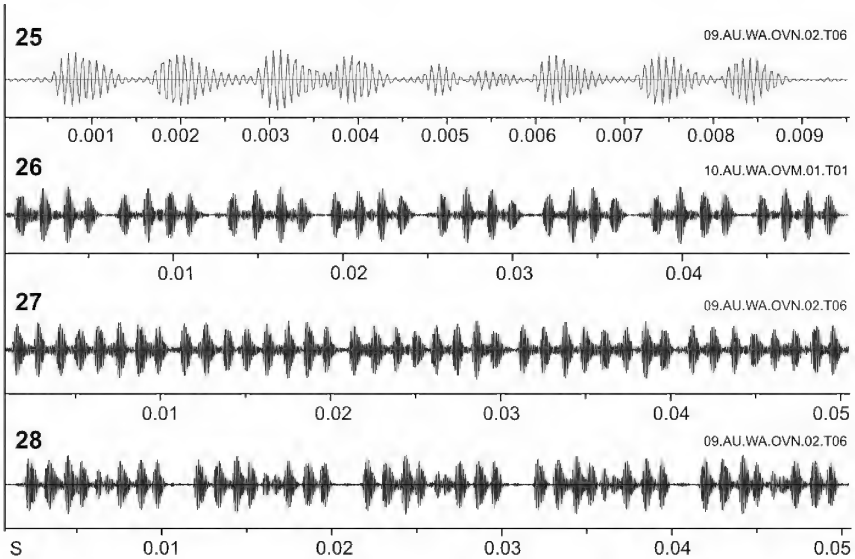
Jassopsaltria rufifacies (Figs 21–24)

Song-recorded specimens. 03.AU.WA.CAT uncollected males (218 s, 24.3 °C); 09.AU.WA.KBB.01 (70 s, 39 °C); 10.AU.WA.GRE.02 (100 s, 27.5 °C); 10.AU.WA.MOX.01 (90 s, temp. not recorded, very hot), 10.AU.WA.MOX site uncollected male (100 s).

Song in *Jassopsaltria rufifacies* consists of pulses of up to about 0.9 ms duration repeated at approximately 740-910/sec (when produced in distinguishable syllables), with minor amplitude variation (Fig. 21), creating a smooth whining buzz of indefinite duration. Pulses are sometimes subtly grouped in 2+1+2 or 4-pulse patterns, and sometimes with 4-pulse syllables subtly grouped into pairs (Figs 22–24). Often in our recordings, pulses appear in extremely irregular patterns for extended periods (e.g., in cage recordings), with the pulse structure itself difficult to consistently distinguish, perhaps due to asynchronous and shifting-phase timbal action; field observations suggest that disturbance may



Figs 21–24. Oscillograms showing song structure and variation in *Jassopsaltria rufifacies* sp. n. Vertical axis is linear amplitude. The code shown for each is the recording track number.



Figs 25–28. Oscillograms showing song structure and variation in *Jassopsaltria aeroides* sp. n. Vertical axis is linear amplitude. The code shown for each is the recording track number.

induce this behaviour. The sound frequency profile is not modulated over time in our recordings; the highest amplitude frequencies are found within the range 10.3–12.7 kHz, and the sound energy is strongest in a frequency band ranging from 9.3–14 kHz (the window within which the amplitude remains within 10 dB of the maximum intensity).

Jassopsaltria aeroides sp. n. (Figs 25–28)

Song-recorded specimens. 09.AU.WA.OVN.02 (55 s, 39 °C); 09.AU.WA.OVN uncollected males (53 s, 39 °C); 09.AU.WA.OVM.01 (temp. not recorded, very hot conditions).

Song similar to that of *Jassopsaltria rufifacies* in the structure of its fundamental pulses (Fig. 25). Steadily repeated 4-pulse syllables (Fig. 26) and 2-syllable macrosyllable arrangements (Figs 27–28) appear most common in our recorded sample, but more data will be needed to confirm this. All of these forms yield a similar overall pulse rate of about 770–940/s. Unlike all other *Jassopsaltria* studied so far, males of *J. aeroides* often irregularly and sometimes rhythmically modulate the sound frequency spectrum up and down, with the upsweep faster than the downsweep, producing revving waves occurring approximately every 1–3 s. This behaviour may be associated with either disturbance or courtship. Occasional frequency modulation in the other species studied, if present, is erratic and less pronounced. Measurements of the sound spectrum yield similar results to those of *J. rufifacies* at the upper end of the oscillations, with a shift of approximately 0.5–1 kHz in the peak frequency down to the lower range of the oscillation.

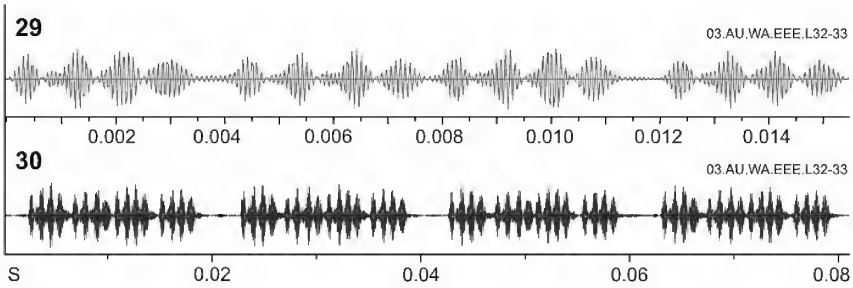
Jassopsaltria danielsorum sp. n.

Song not recorded.

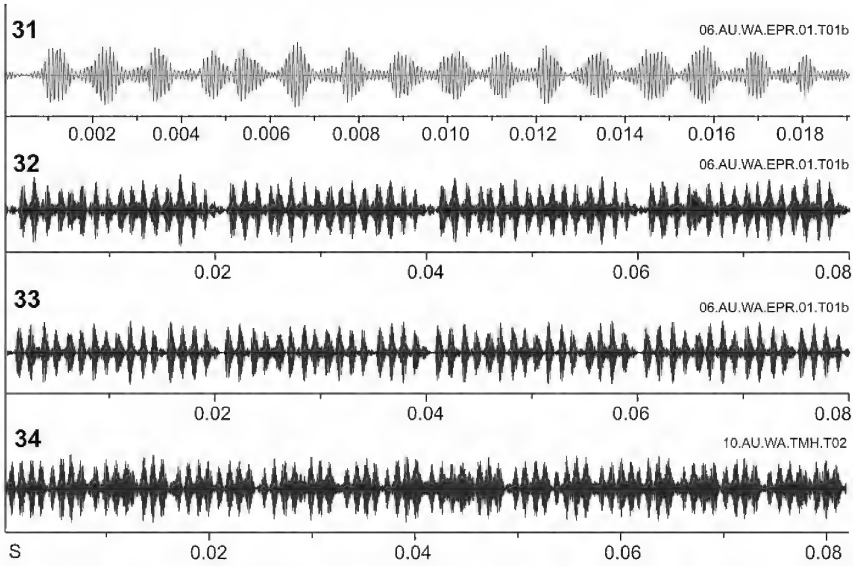
Jassopsaltria cinnamomea sp. n. (Figs 29–30)

Song-recorded specimens. 03.AU.WA.EEE uncollected male (71 s, 37.1 °C).

Song again similar to that of *Jassopsaltria rufifacies* in the structure of its fundamental pulses (Fig. 29) and, also as in *J. rufifacies*, produced as a steady whining buzz of indefinite duration. In its higher order structure, *J. cinnamomea* differs from both *J. rufifacies* and *J. aeroides* in that the pulses are grouped into sets of four syllables, each with four pulses (Fig. 30). The pulses are produced at about 1100–1200/s, the syllables are produced at about 250/s, and the macrosyllables themselves at about 51/s (keeping in mind that all of these measurements are presumably temperature-dependent, and that only one recording was obtained). The peak frequency varies from 10.8–12.8 kHz, with the main (+/- 10 dB) sound energy ranging from 10.3–13.3 kHz and showing no frequency modulation. The buzz is coarser in quality than in either *J. rufifacies* or *J. aeroides* In most of the 4-syllable macrosyllables, the gap between the second and third syllables is slightly shorter (as figured), but sometimes the first or third gaps are shorter.



Figs 29, 30. Oscillograms showing song structure in *Jassopsaltria cinnamomea* sp. n. Vertical axis is linear amplitude. The code shown for each is the recording track number.



Figs 31–34. Oscillograms showing song structure in *Jassopsaltria gracilens* sp. n. Vertical axis is linear amplitude. The code shown for each is the recording track number.

Jassopsaltria gracilens sp. n. (Figs 31–34)

Song-recorded specimens. 06.AU.WA.EPR.01 (19 s, 31.5 °C); 06.AU.WA.EPR uncollected male (32 s, 31.5 °C); 10.AU.WA.WOL.02 (75 s, < 8:40 AM); 10.AU.WA.WOL uncollected male tracks (13 s, 50 s, 38 s, < 8:40 AM); 10.AU.WA.TMH uncollected male tracks (10 s, 5 s, mid-30's °C).

Song with fundamental pulses structured as in the preceding species (Fig. 31). Higher order structure sometimes similar to that of *J. cinnamomea*, with 4-syllable macrosyllables consisting of 4-pulse syllables (Figs 32–33). Other recordings lack clear macrosyllable structure, and some sections exhibit repeated single

or double syllables (Fig. 34). Repetition rates of pulses and syllables are about 760–1000/s and 180–230/s respectively, for the 4-syllable song form, somewhat slower than in *J. cinnamomea*, but the only *J. cinnamomea* recording was made at a much higher temperature. Notably, the macrosyllable repetition rate is again around 50/s (40–60), in part due to their closer spacing. Peak frequencies range from about 9.9–12.3 kHz, with the main sound energy found within the range 9–12.9 kHz. Unlike the preceding species, song is regularly produced in bouts of usually 2–9 seconds in length, separated by silent gaps of about 1–5 seconds. Males sometimes utter little buzzes after the main call (K. Hill pers comm.).

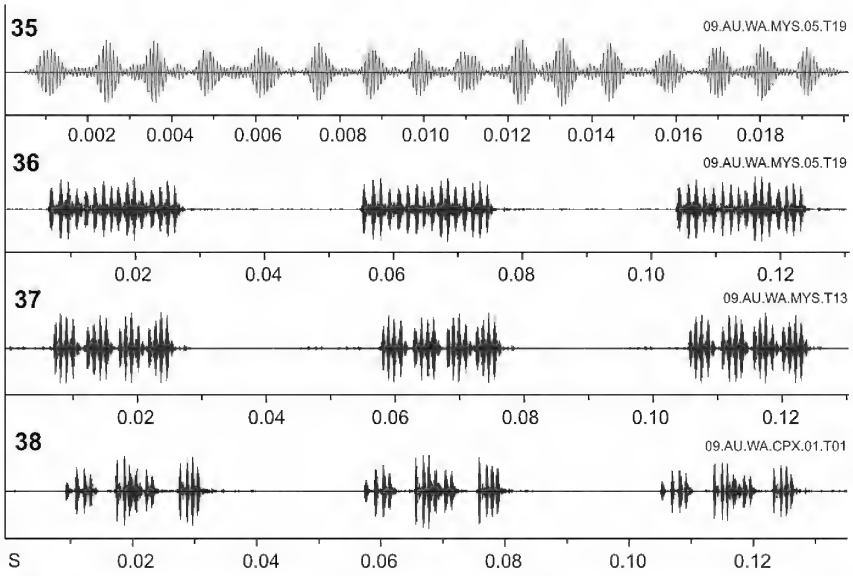
Jassopsaltria minilyaensis sp. n. (Figs 35–38)

Song-recorded specimens. 09.AU.WA.CPX.01 (60 s, ≈40 °C); 09.AU.WA.CPX.01 (45 s; ≈40 °C). 09.AU.WA.NAS.01 (36 s). 09.AU.WA.MYS.02 (95 s); 09.AU.WA.MYS.05 (73 s); 09.AU.WA.MYS uncollected male tracks (80 s, 49 s, 15 s, 52 s). (All WA.MYS recordings 9:20–11:40AM, with temperature 38 °C by 11:40AM.)

Song pulse, 4-pulse syllable, and 4-syllable macrosyllable structure resembling *J. cinnamomea* and *J. gracilens*, but distinctive in having the macrosyllables widely separated and produced at a rate of about 18–22/s, with the gaps between them longer than the macrosyllables themselves (Figs 35–38). This allows the separate macrosyllables to be easily distinguished by the human ear. Pulses within syllables are also sometimes produced with a markedly decreasing rate. Despite the much slower macrosyllable repetition rate, the syllable repetition rates within macrosyllables and the pulse repetition rates within syllables are approximately 900/s (700–1100) and 190/s (160–220), about the same as in *J. gracilens*. Thus, temperature differences alone are unlikely to account for the slow macrosyllable repetition rate in *J. minilyaensis*. Song bouts continue for indefinite periods. Peak frequencies range from about 10.5–12.4 kHz, with the main sound energy found within the range 9.5–13.7 kHz.

Discussion

The song descriptions, while based on the limited material available, are sufficient to show that the songs are minimally divergent in most cases (Figs. 21–38) (*Jassopsaltria danielsorum* has not yet been recorded). The considerable variation in pulse pattern observed within some song bouts of individual males is a contributing factor. Only the song of *J. minilyaensis*, with its staccato song caused by widely spaced macrosyllables, differs to a degree that makes it easily distinguishable from all recordings of the other species in its fundamental pattern of syllables and macrosyllables (keeping in mind that only few localities have been examined). In addition to this, the species that produce 4-syllable macrosyllables (*J. cinnamomea*, *J. minilyaensis*, and *J. gracilens* in some recordings) can be distinguished as a group from *J. rufifacies* and *J. aeroides*, which exhibit either no syllable grouping or macrosyllables with fewer syllables. *J. aeroides* can be distinguished by its often-rhythmic frequency modulation, and *J. gracilens* is distinguishable by its habit of producing short song bouts separated by silent gaps. *J. rufifacies* and *J. cinnamomea* are the most similar, but a careful ear



Figs 35–38. Oscillograms showing song structure in *Jassopsaltria minilyaensis* sp. n. Vertical axis is linear amplitude. The code shown for each is the recording track number.

can detect the coarser quality of the buzz in the latter species, created by the macrosyllable structure. Because none of the species have yet been found in sympatry, it remains possible that none of the song differences are sufficient to confer premating reproductive isolation, a situation that has been observed in some parapatric cicada species and subspecies complexes (e.g., Popple 2013, Hertach *et al.* 2015, Marshall & Hill, 2017). Further work should focus on areas of potential contact between the species.

Acknowledgements

For access to the type of *Jassopsaltria rufifacies* in the SAM we thank Jane Forrest. We are especially grateful to David Rentz for photographing the specimens used in Figs 7–12. For the genitalia drawings of *Jassopsaltria rufifacies* we thank Kyra Kopestonsky, for the wing drawings we thank Hannah Matthews, while all other drawings of genitalia were done by Ivan Nozaic; to all three people we express our sincere thanks. Kathy Hill participated in field collection efforts and took the photographs of live specimens. We thank Paul Hutchinson, David Emery and Lindsay Popple for helpful comments on the manuscript. Specimens were collected under permits to MSM, DM and K. Hill (permit numbers SF007173, CE002260, SF006180, SF005275 and SF003997) from the Western Australian Department of Environment and Conservation. Financial support was provided by NSF grants DEB1655891, DEB0955849, DEB0720664, DEB0529679, and DEB0089946 to C. Simon, D. Marshall, J. Cooley, M. Villet and M. Moulds.

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RECORDS OF *HYPOCHRYSOPS* C. AND R. FELDER, 1860 BUTTERFLIES (LEPIDOPTERA: LYCAENIDAE: LYCAENINAE) FROM NORTHERN TORRES STRAIT, QUEENSLAND

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Abstract

Historic and current records for *Hypochrysops* C. and R. Felder species are presented from northern Torres Strait, Queensland. *Hypochrysops narcissus eratosthenes* (Fruhstorfer) is recognised for the first time in Australia from Dauan Island. The first males of *H. chrysargyrus* Grose-Smith and Kirby are recorded from Saibai Island.

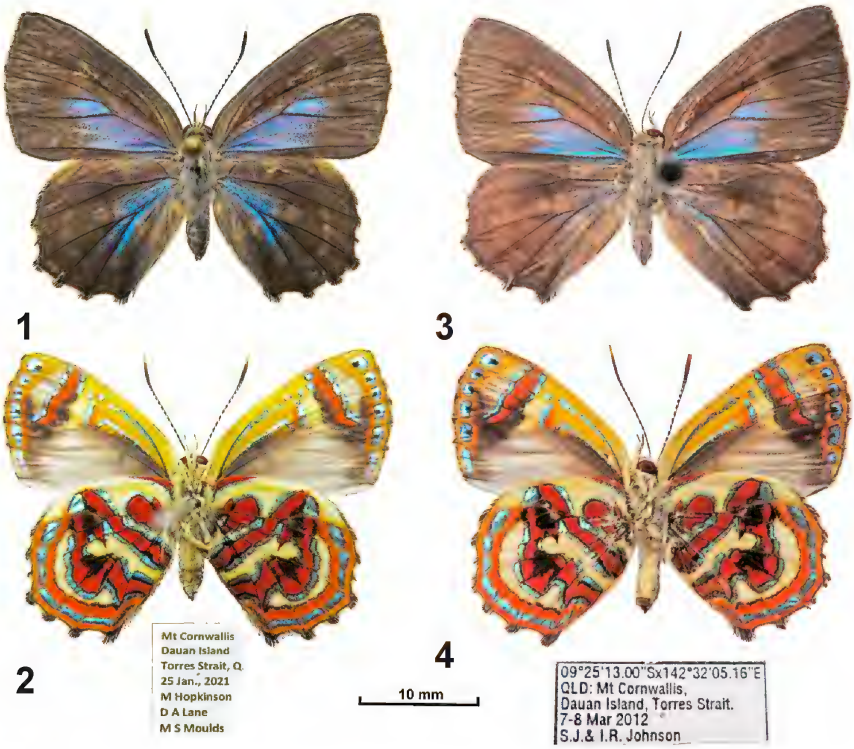
Keywords: Papua New Guinea, vegetation, butterfly surveys, granitic outcrop, mud island.

Introduction

Being part of the State of Queensland, Dauan and Saibai Islands are two of the three (including Boigu) most northern Australian islands lying just off the coast of southern Papua New Guinea in Torres Strait. Located just six kilometres apart, the two islands differ significantly in size, geology and vegetation. Dauan is a relatively small granitic island (approx. 3.4 km^2) with a central high granite peak (Mt Cornwallis) reaching nearly 300 m above sea level (asl). The island is geologically part of the Great Dividing Range of eastern Australia. These features, and its rich vegetation, have been detailed in Anonymous (2013). Saibai is a much larger island (approx. 108 km^2) but has a very low profile (elevation 1–4 m but mostly less than 1 m asl). It consists of alluvial mudflats deposited on decayed coral platforms by adjacent large river systems in southern Papua New Guinea including the Fly River. The principal vegetation is open *Melaleuca* woodlands and grasslands but the island is dominated by wetlands including mangrove and saltpan communities. Mangroves line the entire shoreline apart from a comparatively short distance adjacent to the town (Torres Strait Regional Authority 2016).

Dauan Island has been the subject of fairly intensive butterfly collecting over the past two decades, and with 143 recorded species it has a relatively high butterfly diversity (Lambkin 2021). Saibai Island, on the other hand, has received far less interest from lepidopterists over the same period, partly due to its less appealing vegetation.

Hypochrysops narcissus (Fabricius, 1775) was first collected on Dauan Island by (the late) A.I. Knight in 2001 from blossom not far from mangroves, with additional specimens collected in 2006 and 2008 by A.I. Knight and T.A. Lambkin also from blossom near to mangrove areas (T. Lambkin pers. comm.).

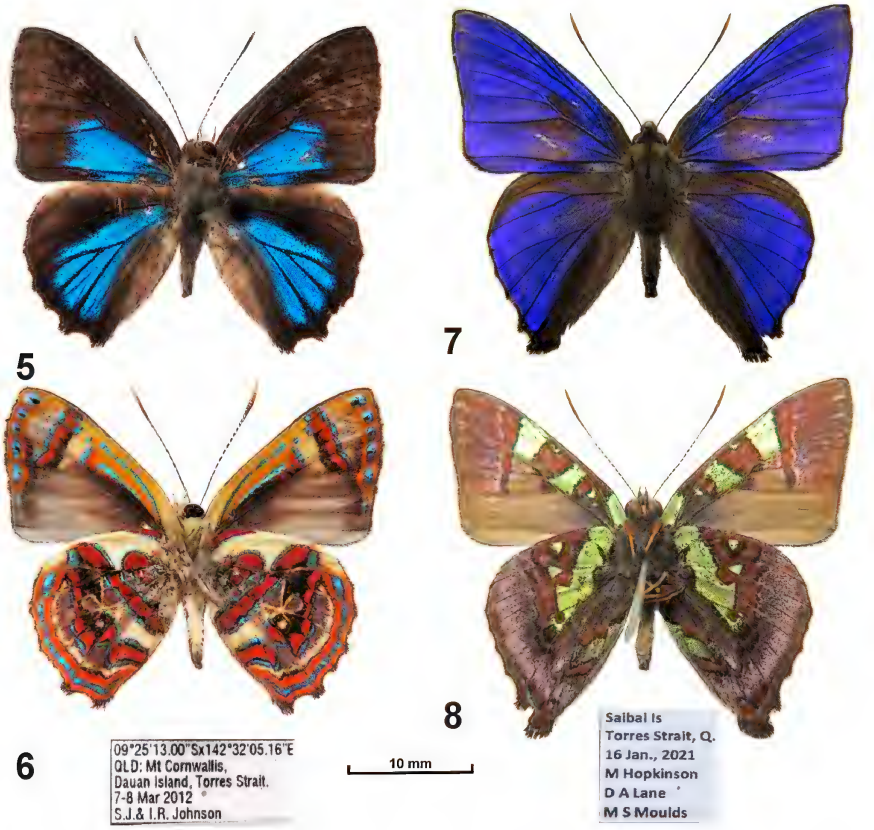


Figs 1–4. *Hypochrysops narcissus eratosthenes*, females, Dauan Island. (1, 3) dorsal; (2, 4) ventral.

Further specimens were collected by (the late) S.J. Johnson and I.R. Johnson in 2005, 2011 and 2017 in mangrove areas as well as on the summit of Mt. Cornwallis (I. Johnson pers. comm.). These records have not been previously published and their subspecific status has not been designated. During January and March, 2021 a pair of *H. narcissus* were collected by one of us (MH) on the summit of Mt. Cornwallis. All known specimens from the island are detailed below, see also Figs 1–6, Specimen records and Discussion. We have determined all these specimens to be subspecies *H. n. eratosthenes* (Fruhstorfer, 1908), previously unrecognised from Australia.

Specimen records

Abbreviations for collection depositories: DALC—David Lane Collection, Atherton; MHC—Mark Hopkinson Collection, Kamerunga, Cairns; MTQC—Museum of Tropical Queensland Collection, Townsville; TALC—T.A. Lambkin Collection, Brisbane.



Figs 5–8. *Hypochrysops* species, Dauan and Saibai Islands. (5, 6) *H. narcissus eratosthenes*, male, (5) dorsal; (6) ventral, Dauan Island. (7, 8) *H. chrysargyrus* male, (7) dorsal; (8) ventral, Saibai Island.

Hypochrysops narcissus eratosthenes (Fruhstorfer, 1908) (Figs 1–6)

QUEENSLAND: 3 ♂♂, Dauan Is, Torres Strait, 5.v.2001, 4.i.2008, 31.i.2008, A.I. Knight; 2 ♂♂,1 ♀, Dauan Is, Torres Strait, 9.i.2006, 14.i.2008, T.A. Lambkin (all TALC); 3 ♂♂ (Figs 5–6), 1 ♀ (Figs 3, 4), 9°25'13"S, 142°32'05.16"E, Mt Cornwallis, Dauan Is, Torres Strait, 7–8.iii.2012, S.J. Johnson & I.R. Johnson; 1 ♀, 9°25'12.60"S, 142° 32'04.58"E, Dauan Island, Torres Strait, 21–23.iii.2011, S.J. & I.R. Johnson; 1 ♂, Dauan Island, Torres Strait, 9.4120°S, 142.5327°E, 7.iii.2005, S.J. & I.R. Johnson; 1 ♂, Dauan Is., Torres Strait, 15–22.v.2017, I.R. Johnson [first label], QM Reg No T240511 [second label] (all MTQC); 1 ♀, Mt Cornwallis, Dauan Is, Torres Strait, 25.i.2021, M. Hopkinson, D.A. Lane, M.S. Moulds (Figs 1, 2); 1 ♂, Mt Cornwallis, Dauan Is, Torres Strait, 22.iii.2021, M. Hopkinson, B.R. Holmes (both MHC).

***Hypochrysops chrysargyrus* Grose-Smith & Kirby, 1895** (Figs 7, 8)

QUEENSLAND: 1 ♂, Saibai Is., Torres Strait, 16.i.2021, M. Hopkinson, D.A. Lane & M.S. Moulds (MHC) (Figs 7, 8); 2 ♂, Saibai Is., Torres Strait, 17–18.i.2021, D.A. Lane, M. Hopkinson & M.S. Moulds (both DALC).

Discussion

Hypochrysops narcissus is a widely distributed species occurring from Halmahera, Waigeo, Aru, Schouten Islands, mainland New Guinea, through the islands of Torres Strait to north-eastern Queensland (Parsons 1998). The nominotypical subspecies *H. n. narcissus* (Fabricius, 1775) occurs along the east coast of Queensland from about Princess Charlotte Bay to near Bluewater approx. 45 km north-west of Townsville (Braby 2000). Another Australian subspecies, *H. n. sabirius* (Fruhstorfer, 1908), is found in the southern Torres Strait Islands and northern Cape York Peninsula (Sands 1986, Braby 2016), with a suggestion that specimens from the central Torres Strait islands (including Moa and Badu) may also be *H. n. sabirius* (Braby 2000).

In Papua New Guinea subspecies *H. n. dryope* Grose-Smith & Kirby, 1895 occurs widely north of the Central Cordillera, whilst subspecies *H. n. eratosthenes* (Fruhstorfer, 1908) is known mainly from south of the Central Cordillera (Parsons 1998). Parsons (1998) discusses and compares the two Papua New Guinea subspecies of *narcissus*, and illustrates subspecies *eratosthenes* (Plate 46, ♂, figs 1155/1156, Plate 47 fig 1157; ♀, Plate 47 figs 1164/1165). The average forewing length of Papua New Guinea *narcissus* is cited by Parsons as: male 17 mm, female 18 mm (for both subspecies).

A series of *H. n. sabirius* from Moa Island, central Torres Strait (MTQC) as well as from Hammond and Thursday Islands in southern Torres Strait, and from Weipa, Cape York Peninsula (DALC, MHC, MTQC) were compared with the Dauan Island specimens. Specimens from Dauan Island were considerably larger [♀ (n=3) average forewing length 18.2 mm, wingspan 39 mm; ♂ (n=6) average forewing length 17.5 mm, wingspan 37.5 mm] compared to those from Hammond Island and Weipa [♀ (n=8) average forewing length 16.6mm, wingspan 34 mm; ♂ (n=29) average forewing length 16.1 mm, wingspan 34.9 mm). Further, both males and females from Dauan Island have considerably reduced upper central blue areas on both fore- and hindwings, more noticeable in females, than those from Hammond and Thursday Islands and Weipa. The four male specimens from Moa Island (MTQC) that we examined are indistinguishable from southern Torres Strait specimens except for being very slightly larger (n=4, average forewing length 16.5 mm, wingspan 36 mm), but nevertheless still smaller than the Dauan Island specimens. Given the larger size of Dauan Island specimens, in combination with their much reduced upper blue fore- and hindwing areas, the Dauan Island specimens are noticeably distinct and considered more strongly aligned with subspecies *eratosthenes* from southern New Guinea. Hence the Dauan Island specimens are here referred to *H. n. eratosthenes*, and the preceding listed specimens (11 males, 4 females) represent the first Australian records of

this subspecies. Specimens from central (Moa Island) and southern Torres Strait and northern Cape York Peninsula are *H. n. sabirius*.

Foodplant records for *H. narcissus* in Australia include a diverse array of families, including Combretaceae, Loranthaceae, Myrsinaceae, Myrtaceae, Verbenaceae and Viscaceae. As both sexes of *H. n. eratosthenes* have been collected in lowland areas as well as on the summit of Mt. Cornwallis, it seems probable that the species may be breeding in both areas.

Hypochrysops chrysargyrus is a New Guinea species and is widely spread throughout the mainland of Papua New Guinea, although it is sporadic in its appearance (Parsons 1998). Males frequent the damp sand and mud of creek margins, where they have the habit of walking over pebbles and stones for short distances, and stopping intermittently to imbibe mineralised water. Very few females are known (Parsons 1998, C. Müller pers. comm.).

During January, 2021, three males of *H. chrysargyrus* were collected while feeding at blossom of *Terminalia subacroptera* Domin (Combretaceae) along the esplanade road, Saibai Island, by two of us (DAL, MH), (all three specimens are detailed above). A female of this species was previously recorded from Saibai Island by Lambkin & Knight (2005) that to date is the only record of the species from Australia. In consideration of the sixteen year gap between records, the recent collection of three fresh males taken feeding at blossom gives added consideration of the permanent residency of the species on Saibai Island. A search of the area did not find any signs of Taun, *Pommetia pinnata* J.R. Forst. & G. Forst (Sapindaceae), a foodplant tree listed in Parsons (1998), however several other species of Sapindaceae do occur on Saibai and may prove to be used as a foodplant. As some *Hypochrysops* species appear to be quite cryptic in their behaviour and habits, and are often sedentary, further effort is required to find the life history of *H. chrysargyrus* in order to determine its residency on the island.

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NEW STATUS FOR *THERETRA INSULARIS AMBRYMENSIS* LACHLAN, 2004 (LEPIDOPTERA: SPHINGIDAE) FROM VANUATU

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Abstract

Theretra insularis ambrymensis Lachlan is raised to specific rank as *Theretra ambrymensis* Lachlan **stat. n**., based on morphological and molecular evidence.

Keywords: Ambrym, Vanuatu, DNA barcode divergence, morphology

Introduction

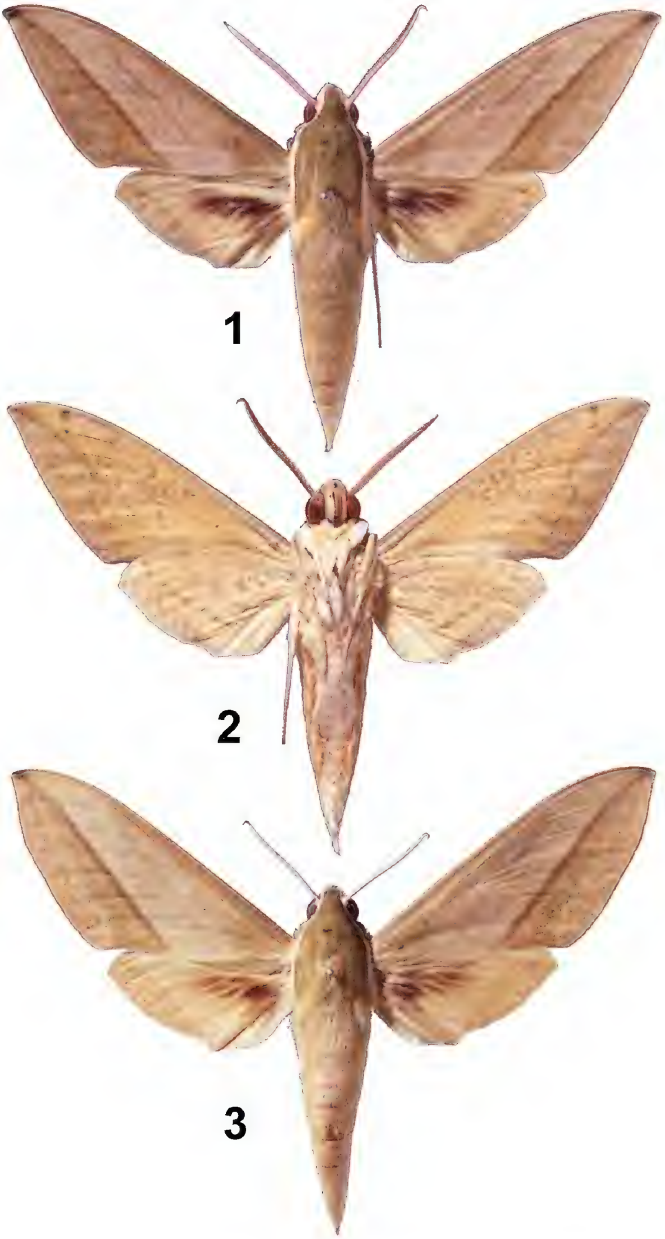
Theretra insularis ambrymensis Lachlan, 2004 from Vanuatu was described as a subspecies of *Theretra insularis* (Swinhoe, 1892) based primarily on a number of external and male genitalia morphological differences that indicated it was most similar to *T. insularis lenis* Jordan, 1926 from in the Solomon Islands (Tennent 1999). However, there is a very large geographical distance of about 850 km, mostly the Coral Sea, between the ranges of the two subspecies and it is intriguing also to note that *T. insularis ambrymensis* has so far, only been recorded from Tongoa Island, Ambrym Island and more recently Epi Island. These islands lie close to one another in the central region of Vanuatu. Despite extensive collecting by the author over many years on the islands in the far north and south of the Vanuatu archipelago, no specimens of *T. insularis ambrymensis* have ever been recorded outside this relatively small, central group of islands. This prompted me to revisit the taxonomic status of *T. insularis ambrymensis.*

Methods and results

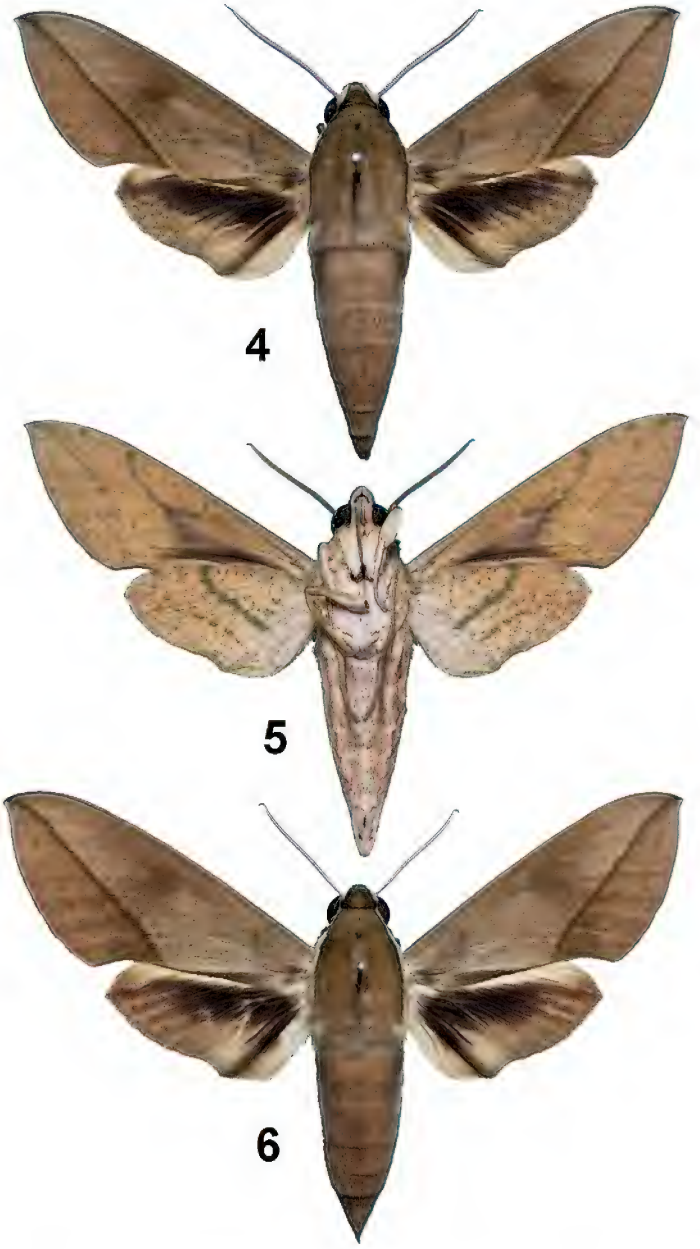
Samples of *T. insularis ambrymensis* were provided to the Barcode of Life Data Systems project (BOLD), for analysis, and the returned DNA barcodes indicated that not only was this taxon 2.44% divergent from any other closely related *Theretra* Hübner, 1819 species but that its nearest species neighbour was not *T. insularis* as previously believed but *Theretra celata* (Butler, 1877). There was an even greater divergence of at least 4.13% between *T. insularis ambrymensis* and *T. insularis lenis* (Table 1), suggesting the possibility of full species status for the former, and prompting the author to revisit the morphology of *T. insularis ambrymensis* in relation to *T. insularis lenis, T. celata celata* and *T. lifuensis* Rothschild, 1894 specimens of both sexes.

Theretra c. celata is recorded from Australia and the Solomon Islands (Moulds *et al.* 2020) but not from New Caledonia (south-west of Vanuatu), where it is replaced by *Theretra lifuensis*. Neither of these species has been recorded from Vanuatu.

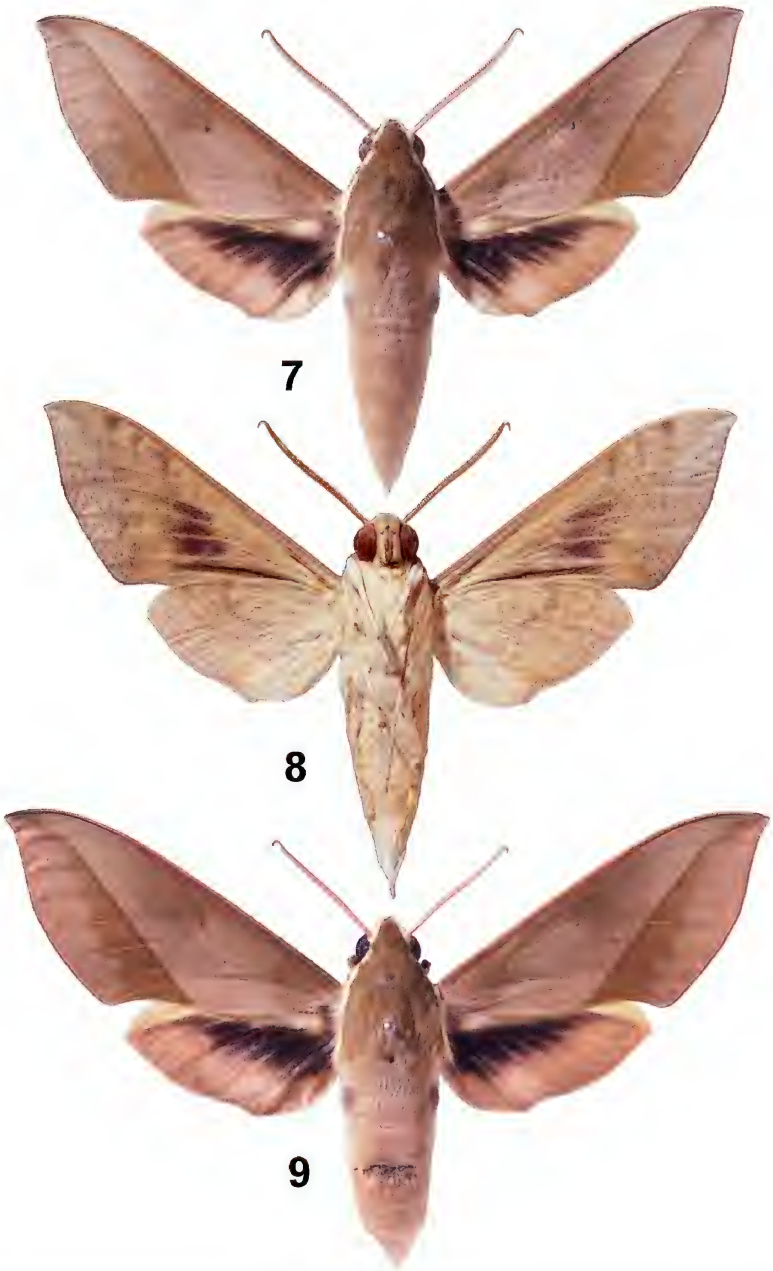
The morphological re-evaluation led to the recognition of many differences separating *T. insularis ambrymensis, T. i. lenis, T. c. celata* and *T. lifuensis.*



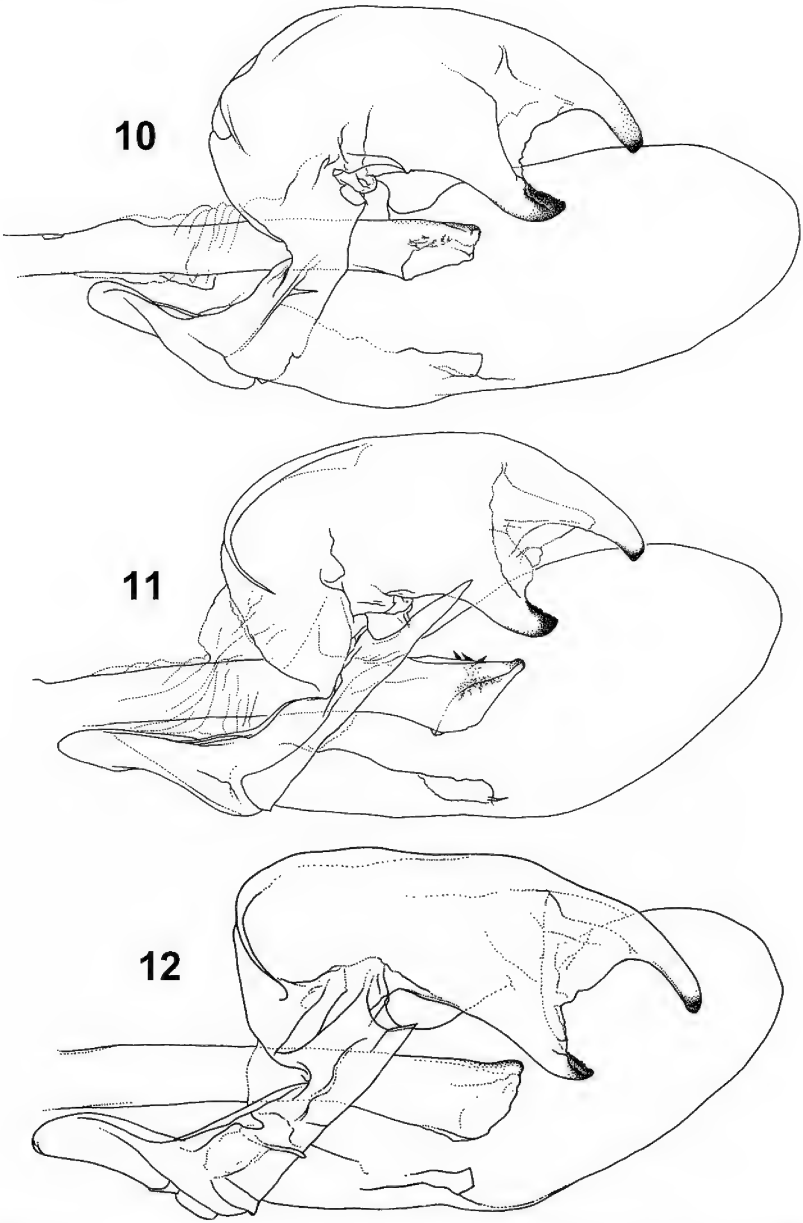
Figs 1–3. *Theretra ambrymensis* stat. n. (1, 2) holotype male: (1) upperside; (2) underside. (3) paratype female, upperside.



Figs 4–6. *Theretra celata celata*. (4, 5) male: (4) upperside; (5) underside. (6) female, upperside.



Figs 7–9. *Theretra lifuensis.* (7, 8) male: (7) upperside; (8) underside. (9) female, upperside.



Figs 10–12. Male genitalia of *Theretra* spp. All genitalia *in situ* but with left valva removed, lateral view. (10) *T. ambrymensis* stat. n. paratype, Ambrym I., Vanuatu; (11) *T. celata celata,* Lizard I., Queensland; (12) *T. lifuensis,* Lifou I., Loyalty Islands, New Caledonia.

Theretra insularis ambrymensis (Figs 1–3) is distinctly larger than *T. i. lenis* and *T. c. celata* (Figs 4–6), with forewing lengths ranging from 41–45.7 mm (n=8) in males and 47.5–52 mm (n=12) in females. These compare to forewing lengths of 35–42 mm (n=34) in males and 41.5–48.9 mm (n=25) in females in *T. c. celata* and 37–39 mm (n=12) in males in *T. i. lenis. Theretra lifuensis* (Figs 7–9) is the smallest of the four taxa and clearly not closely related to *T. insularis ambrymensis* based on its external morphological characters alone.

The general ground colour of both male and female *T. insularis ambrymensis* is a distinct light yellowish-green, slightly lighter than in *T. i. lenis* and *T. c. celata.* The females of *T. c. celata* (Fig. 6) are also usually noticeably much darker.

In *T. insularis ambrymensis,* the thorax has four thin, light orange-brown, longitudinal stripes (Fig.1) that are not seen in *T. c. celata* and are less prominent in *T. i. lenis.* A small, suffused, dark lateral abdominal patch, close to the thorax, is clearly visible on *T. c. celata*, reduced in *T. i. lenis* but greatly reduced in intensity in *T. insularis ambrymensis* to the point of being barely visible.

The termen of the forewings of *T. insularis ambrymensis* tends to be straighter than that of *T. c. celata,* particularly in males, and on the forewing upperside the small, dark, medial patch near the costal margin of *T. c. celata* is absent on *T. insularis ambrymensis.* The forewing upperside in *T. insularis ambrymensis* (Fig.1) also has a narrow, dark greenish brown medial stripe from the apex to the inner margin, with slightly ill-defined edges. In *T. c. celata* (Fig.4), this medial stripe is thinner and darker with well-defined edges. The obvious forewing discal spot seen clearly in *T. c. celata* varies between prominent to barely visible in *T. i. lenis* and is absent on almost every specimen examined of *T. insularis ambrymensis.* Just one male and one female examined exhibited a very tiny discal spot.

Theretra insularis ambrymensis has three additional, parallel, longitudinal stripes anterior of the main dark medial stripe, of which, the inner two are generally faint or vestigial, whereas in *T. i. lenis* they tend to be more prominent. Occasional specimens of *T. c. celata* show vestigial stripes in the same position. The single, thin sub-basal band enclosing a slightly dark basal region on the forewings above of *T. insularis ambrymensis* and *T. c. celata* is completely absent in *T. i. lenis.*

The basal area of the hindwings above in *T. insularis ambrymensis* (Fig.1) is suffused with black and covers less than one third of the wing area, whereas in *T. i. lenis* this black area is larger, extending distally along the costal region almost to the apex. In *T. c. celata* (Fig.4), this black region is much more expansive, covering almost the whole wing. In the hindwing of *T. insularis ambrymensis* there is a faint yellowish green terminal band running from the apex to the tornus with an obvious straight inner edge. This band is speckled with black scales. In *T. i. lenis* the inner edge of this band is clearly less distinct.

The male genitalia of *T. insularis ambrymensis* and *T. c. celata* are similar but there are a number of differences that allow them to be separated. No specimens

Table 1. Divergence percentages between the pairs of *Theretra* specimens selected for analyses as recorded on the Barcode of Life Data Systems project (BOLD). Generally, the greater the divergence, the less the similarity between the compared species.

Species and Country	BOLD Sample ID codes	Species and Country	BOLD Sample ID codes	Divergence %
Theretra celata celata Qld, Australia.	ANICC006-08	*Theretra celata babarensis* Maluku, Indonesia.	SPTMA491-07	1.01
Theretra celata Solomon Is.	SARBF091-13	*Theretra celata celata* Qld, Australia.	ANICC006-08	1.34
Theretra celata Solomon Is.	SARBF091-13	*Theretra celata babarensis* Indonesia.	SPTMA491-07	1.52
Theretra i. insularis Western Prov., PNG.	SPHRL015-19	*Theretra insularis lenis* Solomon Is.	SARBF085-13	2.00
Theretra insularis ambrymensis	**SPHRL010-19**	***Theretra celata*** **Solomon Is.**	**SARBF091-13**	**2.44**
Theretra insularis ambrymensis	**SPHRL010-19**	***Theretra celata celata*** **Qld, Australia.**	**ANICC006-08**	**2.86**
Theretra celata Solomon Is.	SARBF091-13	*Theretra insularis lenis* Solomon Is.	SARBF085-13	3.21
Theretra insularis ambrymensis	**SPHRL010-19**	***Theretra celata babarensis*** **Indonesia.**	**SPTMA491-07**	**3.36**
Theretra insularis lenis Makira, Solomon. Is.	SARBF085-13	*Theretra celata babarensis* Indonesia.	SPTMA491-07	3.51
Theretra insularis lenis Makira, Solomon. Is.	SARBF085-13	*Theretra celata celata* Qld, Australia.	ANICC006-08	3.70
Theretra insularis ambrymensis	**SPHRL010-19**	***Theretra insularis lenis*** **Solomon Is.**	**SARBF085-13**	**4.13**
Theretra insularis ambrymensis	**SPHRL010-19**	***Theretra i. insularis*** **Western Prov., PNG.**	**SPHRL015-19**	**4.47**
Theretra i. insularis Western Prov. PNG.	SPHRL015-19	*Theretra celata* Solomon Is.	SARBF091-13	4.62
Theretra i. insularis Western Prov. PNG.	SPHRL015-19	*Theretra celata babarensis* Indonesia.	SPTMA491-07	4.62
Theretra i. insularis Western Prov. PNG.	SPHRL015-19	*Theretra celata celata* Qld, Australia.	ANICC006-08	4.71

of *T. i. lenis* were available for dissection, so several specimens of *T. i. insularis* were examined and compared with *T. insularis ambrymensis.*

The valvae of *T. insularis ambrymensis* are almost parallel sided with straightish ventral and dorsal edges, whereas in *T. c. celata,* the valvae are more ovate and in *T. i. insularis* the dorsal and ventral margins are clearly angled upwards. The dorsal point of the harpe in *T. insularis ambrymensis* points forward but in *T. c. celata* it is angled backwards. The saccus in *T. insularis ambrymensis* is distinctly shorter than that of *T. c. celata* and *T. i. insularis.* The uncus, in lateral view, has

the dorsal and ventral surfaces gently curved in *T. insularis ambrymensis* but in *T. c. celata* the dorsal surface is slightly straighter. In *T. i. insularis,* the uncus is thinner than in *T. insularis ambrymensis* and its gnathos is shorter and narrow.

Conclusion

The morphological differences described above, together with the detailed data provided in Table 1 indicating a 4.13% barcode divergence between *T. insularis ambrymensis* and *T. insularis lenis* and a 2.44% barcode divergence between *T. insularis ambrymensis* and *T. celata celata,* lead to the conclusion that *T. insularis ambrymensis* is not a subspecies of *T. insularis* but nor is it a subspecies of *T. celata.* Based on the evidence provided here, *T. insularis ambrymensis* Lachlan is raised to specific rank as *T. ambrymensis* Lachlan stat. n.

Acknowledgements

For comments on the manuscript and final preparation of the plates, I sincerely thank Dr Max Moulds (Senior Fellow, Australian Museum Research Institute, Sydney). Dr Ian Kitching (Natural History Museum, London, UK) is also sincerely thanked for providing a great deal of advice on the manuscript.

I am also very grateful to Dr Rodolphe Rougerie, (Curator, Muséum national d'Histoire naturelle, Paris) for his help in obtaining DNA barcodes from specimens provided by the author and in integrating those along with relevant DNA barcodes from BOLD in genetic distance analyses which was crucial to this work. Dr Ron Brechlin, Germany and Dr Tomas Melichar, Czech Republic, very kindly gave their permission to use some of their *Theretra* records in BOLD. Their Solomon Islands data proved essential to this manuscript.

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A REVIEW OF SOUTHERN RANGE EXTENSIONS FOR *THERETRA INDISTINCTA INDISTINCTA* (BUTLER, 1877) (LEPIDOPTERA: SPHINGIDAE) IN NEW SOUTH WALES

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Abstract

A review of southern range extensions is provided for *Theretra indistincta indistincta* (Butler) in New South Wales. The recent collection of this species from the Macleay Hastings IBRA subregion of the North Coast Biogeographical region, together with relevant internet records from iNaturalist is presented.

Keywords: hawkmoth, distribution, northern New South Wales

Introduction

A major contribution of CSIRO Monographs on Australian Lepidoptera has been a more accurate indication of the geographic range for many moth species. *Hawkmoths of Australia: identification, biology and distribution* Monograph 13

Fig. 1. Female (above) and male (below) of *Theretra indistincta indistincta* collected at Lake Innes, New South Wales.

(Moulds *et al.* 2020) provides detailed distributions for Australian hawkmoths that assists readers to identify new range records. This publication records the distribution of *Theretra indistincta indistincta* to include northern Western Australia south to Broome; east to Darwin and Daly Waters in the Northern Territory; and from the Torres Strait islands extending south along the east coast of Australia, to the "far north east corner of New South Wales" with "a single record from New South Wales from near Brunswick Heads". There are four morphologically similar species of the genus *Theretra* recorded from north-coast New South Wales. *Theretra celata celata* (Butler) is recorded south to Bandon Grove (Dowling and Haines 1963) and to Tuncurry (Moulds *et al.* 2020); *Theretra latreillii* (W.S. Macleay) south to Wollongong, New South Wales (Moulds *et al.* 2020); *Theretra queenslandi* (T.P. Lucas) south to Bega, New South Wales (Moulds *et al.* 2020) and *Theretra tryoni* (Miskin) south to Sydney, New South Wales (Moulds *et al.* 2020).

New and iNaturalist Records

Theretra indistincta indistincta (Butler, 1877)

An adult female was collected by the author at ultraviolet light placed adjacent to mixed eucalypt forest and rainforest near Lake Innes, NSW (-31.496, 152.836), south of Port Macquarie on 18 February 2018. A further three specimens (one female and two males) were collected at the same location on 10 and 19 December, 2020. Identification was confirmed by M.S. Moulds (*pers. comm.*) December 2020) (Fig. 1). Also collected at the same location, were the southern form of *Theretra queenslandi* (December) and *Theretra latreillii* (November and March).

Southern range extensions from New South Wales of adults drawn from iNaturalist include: Dorrigo, Cundletown, Tinonee, near Taree and a record of a larva at Winnererremy Bay near Mona Vale in Sydney (Appendix 1). These records, as well as those from Lake Innes, show the distribution of *T. indistincta indistincta* is quite extensive in New South Wales and extends as far south as northern Sydney.

Acknowledgement

I thank Max Moulds for confirming the identity of *Theretra indistincta indistincta.*

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Appendix 1.

iNaturalist records for *Theretra indistincta indistincta* in NSW.
(Accessed 5 October 2021).

Tallowwood Ridge, Dorrigo:
23 February 2020 https://www.inaturalist.org/observations/82772656
Bull Hill, Tinonee:
26 December 2019 https://www.inaturalist.org/observations/36950836
Tinonee, near Taree:
1 December 2016 https://www.inaturalist.org/observations/4674961
18 December 2016 https://www.inaturalist.org/observations/4794262
Cundletown, near Taree:
16 December 2017 https://www.inaturalist.org/observations/9659097
12 March 2019 https://www.inaturalist.org/observations/28723387
25 April 2020 https://www.inaturalist.org/observations/43557597
Winnererremy Bay near Mona Vale, Sydney:
21 March 2021 https://www.inaturalist.org/observations/82400148

Book Review

The man who shot butterflies by John Tennent. Storm Entomological Publications, Oxford. 603 pages, lavishly illustrated. £89 + postage. Available at the author's web site (https://www.johntennent.co.uk).

This is another masterpiece by John Tennent. His acclaimed *Butterflies of the Solomon Islands* and *Butterflies of Vanuatu* are two of his others, both authoritative works well known to butterfly researchers and enthusiasts.

The man who shot butterflies is an account of the amazing life of Albert Meek (1844–1931) whose passion for butterflies, birds and adventure had no bounds. I cannot describe Meek better than in the words from the author's web site quoted here: "Albert Stewart Meek – was one of the last great collectors of natural history specimens, literally thousands of which were new to science. Sponsored by Walter Rothschild and curators at Rothschild's private museum at Tring, Meek was one of the most successful southwest Pacific explorers and adventurers of his time: a period of history when many missionaries, traders and gold miners died from fever or were killed and eaten by cannibals. A highly focused but modest man, Meek suffered unimaginable physical hardships in reaching parts of New Guinea and the Solomon Islands where no-one had been before. More than 100 of the undescribed species he collected now bear his name."

This is no ordinary biography written by someone pouring over documents in a library. In many ways John Tennent actually lived the life of Meek by actually collecting butterflies on all the numerous islands in the south-west Pacific visited

by Meek some 100 years before. Some of these islands even today remain very remote and dangerous, places where the naive tend to mysteriously 'disappear'. Tennent spent months in these islands in pursuit of butterflies for perhaps another book, living with the locals and climbing all the highest peaks, just as Meek did. This background gave Tennent a genuine insight into the life and character of Meek that enabled him to write this biography in a way that no one else could have done.

This book is packed with previously unpublished information and photographs, all 603 pages of it. I counted 398 photographs and maps. It draws extensively on 500 pages of Meek's letters which were written to Tring curators and now archived in the Natural History Museum, London, and on Meek's personal photograph album now in the care of Sir David Attenborough.

The author has an engaging style that makes this book easy to read, and constantly holds the readers attention with interesting snippets and informative commentary. The pages overflow with interesting and fascinating facts, many of which relate to Meek's extended family, Meek's contemporaries in the world of biology, all skilfully set in the historical perspective of the time.

The book begins with a comprehensive Introduction that details, among other things, the difficulties the author experienced in researching this book. Even this chapter is engaging and shows the author's amazing attention to detail and his dedication to background research, that remain evident throughout the entire work.

Following the Introduction the book proceeds to a chronological account of Meek's life in 20 chapters (424 pp.). Here we get a true picture of Meek, the man, of his extended family, his associates and what life was like in New Guinea and the Solomon Islands at the time. This is where we learn about rifts within the Meek family, his adventures cheating death on several occasions (unlike some others accompanying him). We learn also of Meek's close association with Walter Rothschild of Tring and Meek's never ending pleas for money, of his early days with the Barnard's of

Coomooboolaroo, and of the Eichhorn family (Meek's first wife was Emilie Eichhorn and her brothers had close ties with Meek including accompanying Meek on some of his expeditions, hence the Australian butterflies *Jalmenus eichhorni* and *Euploea alcathoe eichhorni*). Interwoven throughout the text is lots of entomology, particularly about butterflies, but there's much, much more. It is here that the author's extensive commentary, between extracts of Meek's letters, is what makes this book so special. Tennent's boundless knowledge puts everything in perspective, brings the letters to life, and engages the reader to such an extent that one is continually captivated.

The book concludes with an extensive list of Endnotes (many sources of supplementary information), a list of References (over 500), and four Appendices (a summary of Meek's family relationships, a collection of 130 archival photographs, a chronology of significant events, and images of various handwritten notes). An Annex then lists taxa named for Meek and Eichhorn (144 of them), followed by a 17 page Index.

It is interesting that the author's extensive research also reveals that Meek's book, *A naturalist in Cannibal Land* (first published 1913), includes many anomalies that conflict with accounts of the same events in Meek's letters. These errors of fact, Tennent concludes, suggest that much of the book was written by the editor Frank Fox, rather than by Meek, and Meek never saw the final manuscript before it went to press.

The author spent some 25 years researching and writing this book and there is no denying it is an impressive tome, even its size and weight are impressive (it weighs 3.3 kg!). At £89 it is a bargain. I see it as one of the great natural history biographies, one that I'm sure will become a 'collector's item' in years to come. Anyone interested in butterflies, indeed natural history, or in the colonial history of tropical north Queensland and Papua New Guinea, would find this book fascinating. It goes far beyond a good read; it is a serious reference book full of original information, a book that anyone interested in Meek in the broadest sense should have on their bookshelf.

Max Moulds

SUNAITIOTHRIPS MOULTON, 1942 (THYSANOPTERA, PHLAEOTHRIPINAE): QUEENSLAND LEAF-ROLLING THRIPS ON *ACRONYCHIA* (RUTACEAE)

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Abstract

The previously unrecognisable monotypic genus *Sunaitiothrips* Moulton is re-diagnosed, based on the holotype from Cairns District together with fresh material and one new species from southeast Queensland. The two species are remarkably similar in structure and sculpture, but the type species has been found in rainforest inducing leaf galls on *Acronychia imperforata*, whereas *S. ombros* **sp. n.** is known from coastal forest inducing galls on *Acronychia oblongifolia* and *A. suberosa*.

Keywords: Rutaceae, leaf-roll galls, rainforest, new species, Phlaeothripidae

Introduction

The Californian thrips taxonomist, Dudley Moulton (1878-1951), described in 1942 and (posthumously) in 1968 a total of 13 monotypic genera from Australia in the Thysanoptera-Phlaeothripidae. Five of these 13 are now listed as synonyms (ThripsWiki 2021), and most of the others have been fully revised with additional species (ABRS 2021). However, two genera have remained unrecognisable. *Spilothrips* Moulton (1942) is known from three wingless specimens, taken at Bridgetown, Western Australia, that are in a poor condition with few character states visible. *Sunaitiothrips* was collected near Cairns, and the only possible conclusion from the original description was that the genus might be a member of sub-family Phlaeothripinae. The holotype of *Sunaitiothrips fuscus* Moulton (1942) has now been re-studied, and its relationships to other Phlaeothripinae are re-considered together with description of a new species. The two species of *Sunaitiothrips* induce rolled leaf galls on different species of *Acronychia* (Rutaceae) (Fig. 9). The specimens studied and listed below are in the Queensland Primary Industries Insect Collection, Brisbane (QDPC), or in the Australian National Insect Collection, CSIRO, Canberra (ANIC).

Sunaitiothrips Moulton

Sunaitiothrips Moulton, 1942: 1. Type species: *S. fuscus* Moulton, by monotypy.

Moulton distinguished this genus essentially on the presence of two pairs of postocular setae, indicating that this character state was shared with only two other Phlaeothripidae genera - one a monobasic genus from Egypt and the other an unpublished manuscript genus. He also illustrated the presence of two pairs of long epimeral setae on the pronotum but indicated that the inner pair varied in length. Recent examination of the holotype of *S. fuscus*, together with specimens collected recently, indicates that the presence of long setae does not provide a satisfactory indicator of relationships. Setal lengths vary

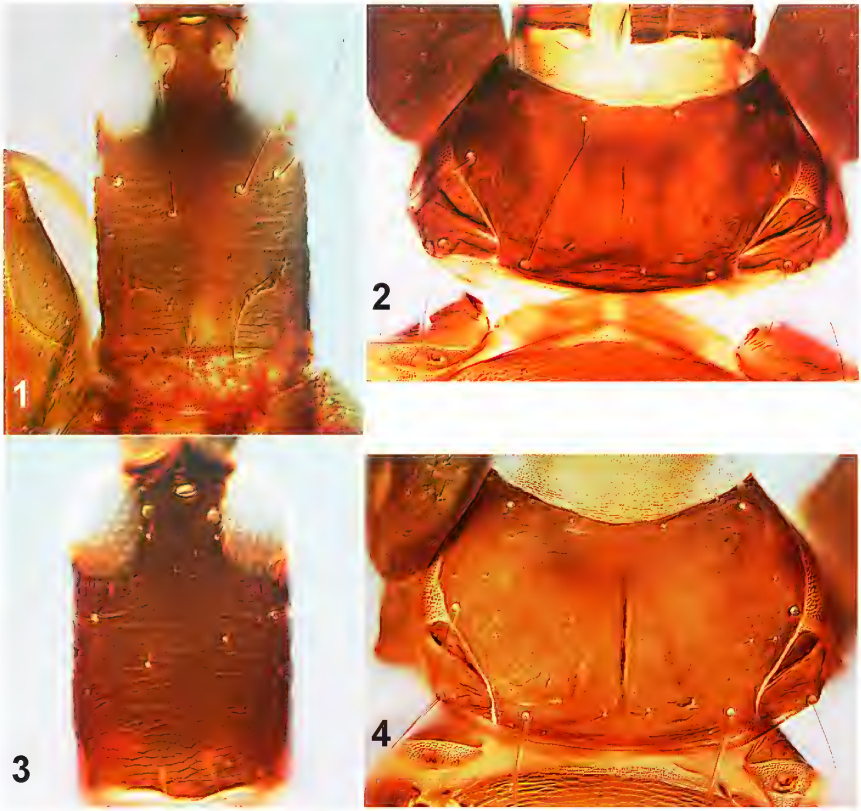
within populations of S. *fuscus*, sometimes on the left and right side of the same individual. Moreover, the second species in the genus described below has neither the cephalic nor the epimeral setae duplicated. The genus is here recognised as a member of the *Teuchothrips*/*Liothrips* complex (Mound 2008), a group that involves a considerable number of undescribed species in Australia that are associated with leaf galls. It shares the following character states with that group of species: antennae 8-segmented, segment III with one sense cone, IV with three sense cones; prosternal basantra absent; mesopresternum variably eroded; metathoracic sternopleural sutures present. As discussed by Mound & Tree (2021), the latter two character states distinguish members of this complex of genera from the gall-inducing Phlaeothripinae in *Gynaikothrips* Zimmerman (1900). However, *Sunaitiothrips* species share with species of *Teuchothrips* Hood (1919) the condition of the pronotal anteromarginal setae being unusually short and the eighth antennal segment also short. From *Teuchothrips* the genus is here distinguished on the following character states that are found both in S. *fuscus* and the new species described below: head clearly longer than wide, with lateral margins parallel and with a small tooth behind each eye; tergites II–VII with only one pair of wing-retaining setae in macropterae and micropterae; tube about 0.6 as long as head with margins weakly convex. In contrast, *Teuchothrips* species have the head as wide as long or only a little longer than wide and with the genae convex, the tergites bear two pairs of wing-retaining setae, and the tube is straight-sided and commonly longer than the head.

***Sunaitiothrips fuscus* Moulton**

(Figs 1, 2)

Sunaitiothrips fuscus Moulton, 1942: 1.

The type series of this species consisted of four females and one male, all macropterae, and the holotype has now been compared with the specimens listed below. This holotype (Fig. 1) is an uncleared specimen, with the pterothorax and abdomen seriously distorted. On the head the outer postocular setae are about 0.8 as long as the head width (175/220 microns), with the inner pair 0.8 as long as the outer pair. Also, on the right-hand side of the pronotum the inner epimeral seta is 0.8 as long as the outer (150/175 microns), but on the left-hand side it is only 0.4 as long. In most of the more recently collected micropterae the outer postocular setae are long and about 0.8 as long as the head width, but the inner postocular setae are shorter, varying from 0.3 to 0.6 as long as the outer pair. Moreover, the inner epimeral setae vary from 0.4 to 0.9 as long as the outer epimeral setae (50/130 – 125/140 microns). The left and right side inner epimeral setae sometimes differ, being minute on one side but elongate on the other (Fig. 2). There is no evidence that these setal lengths might be correlated with wing length, judging from the single recently collected macropterous female listed below. The structural details of *S. fuscus* are essentially identical with the new species described below, but antennal segments III–IV are consistently clear yellow in *fuscus*, with segments V–VI extensively yellow on the basal half.



Figs 1–4. *Sunaitiothrips* spp. (1, 2) *S. fuscus* (1) holotype head; (2) pronotum, female microptera from Noosa. (3, 4) *S. ombros* sp. n. (3) head; (4) pronotum.

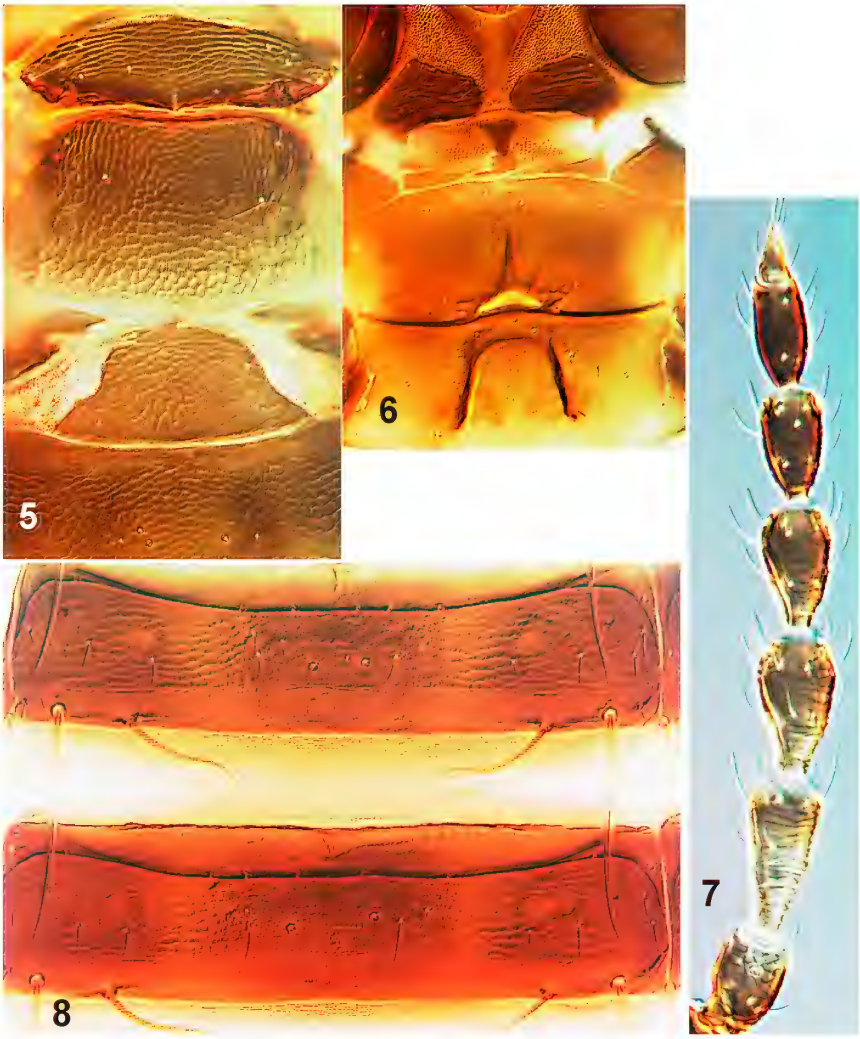
Specimens studied.
Holotype female macroptera, "Cairns District. A.M. Lea", in California Academy of Sciences. **Queensland**: Noosa National Park, 4 female micropterae from *Acronychia imperforata* leaf galls, 14.iv.2007 (DJT451). **New South Wales**: from *Acronychia imperforata* leaf galls: Wooyung Beach, 40km south of Gold Coast, 1 female macroptera, 5 female and 1 male micropterae, 28.xii.2007 (DJT575); Cabarita beach, 30km south of Gold Coast, 7 female and 3 male micropterae, 31.x.2016 (LAM6342).

Sunaitiothrips ombros sp. n.

(Figs 3–9)

zoobank.org:act:DAAE4E94-AB4F-48AE-BBC2-2A1495396456

In structure and reticulation this species is remarkably similar to S. *fuscus*, but it is readily distinguished by the darker antennae and the shorter major setae,



Figs 5–8. *Sunaitiothrips ombros* sp. n. (5) metanotum and pelta; (6) prosternites; (7) antenna; (8) tergites III–IV.

with the postocular setae no more than 0.5 as long as the width of the head, and the minor setae medially on the vertex and epimera small to minute. This is a rainforest species that induces leaf rolls on one or more different species of *Acronychia*, whereas S. *fuscus* is known only from coastal sites.

Female microptera: Body and legs dark brown, tube darkest; fore tibiae paler, fore tarsi almost yellow; major setae all pale; antennal segment II with apex

Fig. 9. *Sunaitiothrips ombros* sp. n. gall on leaf of *Acronychia oblongifolia*.

variably pale, III shaded brown on apical third, IV dark brown in apical half, V brown with base slightly paler, VI–VIII dark brown (Fig. 7). Head more than 1.5 times as long as wide (Fig. 3), genae straight and parallel with small tooth behind eye; ocelli well-developed; vertex with weak transverse sculpture lines, weakly reticulate in ocellar region, median cephalic setae no longer than other minor setae; maxillary stylets retracted halfway to postocular setae. Antennae 8-segmented, III with one sense cone, IV with 3 sense cones; segment VIII short. Pronotum with weak sculpture only near posterior margin (Fig. 4); notopleural sutures complete; inner pair of epimeral setae minute; meso and metanota reticulate (Fig. 5). Prosternal basantra absent; mesopresternum eroded, usually to three small sclerites (Fig. 6); metathoracic sternopleural sutures present. Fore tarsus with large tooth, at least half as long as tarsal width. Fore wing lobe shorter than thorax width. Pelta irregular D-shape, with campaniform sensilla (Fig. 5); tergites weakly reticulate, with group of small setae medially; wing retaining setae short and straight (Fig. 8); lateral tergal setae pointed, shorter than median length of their tergite; tergite IX setae pointed, shorter than tube; tube robust with weakly convex margins, anal setae shorter than tube.

Measurements (holotype female in microns). Body length 3400. Head, length 300; width 210; postocular setae 100. Pronotum, length 230; width 380; major setae – anteromarginal 12, anteroangular 35, epimeral 100; posteroangular 75. Fore wing length 170. Tergite IX setae 140, 130, 130. Tube, length 240; basal width 110. Antennal segments III–VIII length 85, 80, 75, 60, 65, 30.

Female macroptera: very similar to female microptera in sculpture and chaetotaxy but metanotum less transverse, post ocular setae longer, and antennal segments III–IV a little more slender; fore wing light brown medially, but pale

at base including clavus, with about 20 duplicated cilia, only 2 long sub-basal setae; tergites II–VII each with one pair of weakly sigmoid wing-retaining setae.

Measurements (macropterous paratype DJT424, in microns). Body length 3500. Head, length 360; width 210; postocular setae 150. Fore wing length 1450. Tergite IX S1setae 150. Tube length 250. Antennal segments III-VIII length 110, 100, 90, 75, 70, 35.

Male microptera: very similar to female microptera; tergite IX S2 setae almost 70% as long as setae S1.

Measurements (micropterous paratype in microns). Body length 2600. Head, length 280; width 180; postocular setae 65. Pronotum, length 185; width 330; major setae – anteroangular 40, epimeral 80; posteroangular 70. Fore wing 110. Tergite IX setae 125, 70, 65.

Specimens studied

Holotype female microptera, **Queensland**: Lamington, O'Reilly's, in *Acronychia oblongifolia* leaf margin galls, 10.x.2006 (LAM4944), in ANIC.

Paratypes (all micropterae except where indicated): 10 females, 1 male collected with holotype; same locality, date and host, 13 females (DJT353), same locality and host, 3 females, 1 male 11.x.2006 (DJT358), also 1 female, 12.iii.2007 (DJT414); same locality, 2 females, 2 males from gall on *Acronychia* sp., 4.viii.2013 (K. Thomson). O'Reilly's Border track, 1 female, 1 male, 10 female macropterae, from leaf galls on *Acronychia suberosa*, 13.iii.2007 (DJT424). **New South Wales**: Lansdowne, near Taree, 5 females, 2 males, from leaf rolls on *Acronychia oblongifolia*, 13.iv.2002 (LAM4133).

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MANGROVES (RHIZOPHORACEAE) ARE THE PRINCIPAL HOSTS FOR *LYMANTRIA (PORTHETRIA) LUNATA* (STOLL, 1782) (LEPIDOPTERA: EREBIDAE: LYMANTRIINAE) IN NORTHERN AUSTRALIA

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Abstract

New host plants in the Rhizophoraceae are documented for the larvae of *Lymantria lunata* (Stoll) (Erebidae: Lymantriinae). Large numbers of larvae were observed feeding on foliage of *Ceriops* spp. (Rhizophoraceae) at the Jack Barnes Mangrove Boardwalk, Cairns Airport in April 2021. *Rhizophora stylosa* and a *Bruguiera* sp. (both Rhizophoraceae) were inferred as hosts of *L. lunata* in Cairns based on observations of feeding damage and the presence of pupal and larval exuviae on trees. Additional communication with mangrove researchers confirmed these associations, with *R. stylosa* used at Airlie Beach and *B. parvifolia* used in Mackay. Previous host records, eruptive populations and the biosecurity significance of this moth are discussed in respect to these new host plant records. The taxonomic identity of Australian populations of *L. lunata* is questioned in respect to new information on host preferences, and a note on misidentification of Australian *Lymantria* is provided.

Keywords: immatures, larvae, mangroves, herbivory, host plant records

Introduction

In April 2021 during engineering inspections of the Jack Barnes Mangrove Boardwalk (Cairns Airport) numerous larvae of an unidentified moth were observed feeding on mangrove trees. A photo of the larvae was submitted to Cairns-based Northern Australia Quarantine Strategy (NAQS), Department of Agriculture, Water and the Environment (DAWE) entomologists for identification (Fig. 3). The two dorsal glands on abdominal segments six and seven indicated it was in the erebid subfamily Lymantriinae, but the species was not familiar to us. Larvae and pupae were collected for rearing (K. Donnan). A single adult female was reared from these samples and was identified as a species of *Lymantria* Hübner, [1819] by D. Britton.

Reports from the public arrived via the "Report a pest or disease concern" online form (https://www.agriculture.gov.au/pests-diseases-weeds/report, Yorkeys Knob, 3 May 2021) and the NAQS "Report a pest, weed or disease in northern Australia" online form (https://ce.biosecurity.cp1.agriculture.gov.au/, Trinity Beach, 10 May 2021) of large numbers of moths aggregating overnight around lights in coastal suburban areas to the north of Cairns. Images of these moths indicated that they were a species of *Lymantria*. The large numbers of moths at one business resulted in significant cleaning costs for removal of adults and the numerous egg clusters left from female moths, and the first instar larvae that had hatched from these eggs. Concerns were raised over potential human health issues due to the hairs present on these larvae. DAWE entomologists (D. Britton, M. Gorton and V. Toneva) visited one of the affected business locations on 7 May 2021 to observe and collect moth specimens. Adults and egg masses were also

present in large numbers under beachside lights at the Yorkeys Knob location. It was clear that these moths were the same as the specimen reared from mangrove, which resulted in a return trip to the Jack Barnes Mangrove Boardwalk to survey for the moth and damage to putative food plants.

The following results describe the identification of the collected *Lymantria* specimens and outline new host plant records. These results are discussed in relation to existing host plant records, identification and misidentification of Australian *Lymantria*, and the biosecurity status of Australian *Lymantria*.

Specimens of male and female moths collected in this study are deposited in the Northern Australian Quarantine Insect Collection (Cairns, Queensland) and the Australian National Insect Collection (CSIRO, Canberra, ACT).

Rearing

Larvae were collected from trees along the eastern end of the Jack Barnes Bicentennial Mangrove Boardwalk, Cairns International Airport (-16.8837° 145.7612°) (21 April 2021). Numerous larvae and cocoons were observed on the foliage of a common mangrove species present along the Boardwalk. Four larvae and two cocoons were taken for rearing. Two pupae and two larvae died, while a third larva was preserved in 100% ethanol for DNA analysis (Voucher # RD290421). One specimen successfully pupated (25 April 2021), with a female moth emerging 10 days later (5 May 2021).

DNA Analysis

Routine barcoding was conducted, with DNA extracted using a spin column kit Bioline isolate II - genomic DNA kit. The universal barcoding region of the CO1 gene was amplified using a cocktail of the primers from Folmer *et. al.* (1994) and LEP primers from Hebert *et. al.* (2004). Amplicons were isolated and sequenced by AGRF and analysed using Geneious by Biomatters, NZ. The nucleotide sequence is lodged in Genbank under accession number MZ854102.

Identification

***Lymantria* (*Porthetria*) *lunata* (Stoll, 1782) (Erebidae: Lymantriinae)**

Adult male and female moths collected from the Yorkeys Knob locality and from rearing were compared to available descriptions and figures for regional *Lymantria* (Strand, 1923, Schintlmeister, 2004, Pogue and Schaefer, 2007, Horak *et al.*, 2020) (Figs 1, 2). The females of *L. lunata* cannot be confused with any other of the four *Lymantria* species present in Australia. The females of *L. antennata* Walker, 1855 and *L. pelospila* Turner, 1915 are flightless with wings reduced to tiny stubs. *L. nephrographa* Turner, 1915 is a distinctive endemic species where the female resembles the male, an atypical situation for moths in this genus where strong sexual dimorphism is the norm (Horak *et al.* 2020).

In addition to the morphological identification of adult specimens, tissue from a larva from the Jack Barnes Memorial Boardwalk location (RD290421) was

Figs 1, 2. Adult *Lymantria lunata*. (1) Male (2) Female. Collection data: Yorkeys Knob, Queensland, 7 May 2021, D. Britton.

sequenced, resulting in a 682bp contig representing 2 reads, assembled using Geneious with a 100.0% pairwise identity and 98.7% high quality base calls.

This sequence was a 100% match with five published barcodes for specimens of *Lymantria lunata* contained within the Barcode of Life Database (BOLD) BIN: BOLD:AAC6905. All five specimens in this BIN were collected from Queensland, Australia with collection data as follows: 2 females, both from Cairns, 17 August 1962, J.G. Brooks; 3 males, Townsville, Hermit Park, 2 April 2008, G. Cocks; same location and collector, 19 June 2008; 11 April 2009. A BLAST search also found a 99.85% match with GenBank accession number HQ921459 *Lymantria lunata* voucher 10ANIC-01499 (Australia, Queensland, Cairns, 17 August 1962, J.G. Brooks).

New food plant records

- Yellow mangroves *Ceriops* Arn. (Rhizophoraceae) including smooth-fruited yellow mangrove *C. australis* (C.T.White) Ballment, T.J.Sm. & J.A.Stoddart and rib-fruited yellow mangrove *C. tagal* (Perr.) C.B.Rob.
- Small-leafed orange mangrove *Bruguiera parviflora* (Roxb.) Wight & Arn. ex Griff. (Rhizophoraceae)
- Long-style stilt mangrove *Rhizophora stylosa* Griff. (Rhizophoraceae)

Ceriops is native to Australia's northern coastline from Exmouth in the west to the border with New South Wales in the east. The genus is often dominant in the mangrove ecosystems where it is present (Duke, 2006), typically on the landward/saltpan side of mangrove communities on hypersaline soils that receive infrequent inundation (Connolly *et al*., 2006). There is not universal agreement on the species of *Ceriops* present in northern Queensland mangrove communities. *C. australis* is thought to be circumscribed by *C. tagal* by taxonomic authorities in Queensland, while the Australian Plant Census regards both as distinct species (Australian Plant Census, 2021), a position which is well supported by morphological and molecular evidence (Sheue et al., 2009). A third species *Ceriops pseudodecandra* Sheue, H.Y. Liu, C.C. Tsai & Yuen P. Yang is found from the Northern Territory eastwards to the Hinchinbrook

Channel, Cardwell, Queensland. The hypocotyls of mature fruit are required for morphological separation of *C. australis* and *C. tagal*. Fallen fruit were collected at the Boardwalk site and identified as *C. tagal*, but Atlas of Living Australia (ALA) and Mangrove Watch records indicate that *C. australis* is also present at this location (Atlas of Living Australia 2021; Mangrove Watch 2021). At the time of our observations only immature hypocotyls were present on the trees and it was not possible to differentiate between the two species. Based on the presence of damage to leaves and exuviae on the trunks of mature *Ceriops* along the Boardwalk we assume that both species of *Ceriops* in Cairns are utilised as host plants.

While making enquiries around the extent of mangroves in the Cairns region we received additional reports of *L. lunata* defoliating mangrove species in the Rhizophoraceae in areas south of Cairns. At the Pioneer Estuary, Mackay larvae were particularly abundant on *Bruguiera parviflora* in June–July in 2020 and 2021 (Fig. 4) and were found on *Rhizophora stylosa* at Muddy Bay at Airlie Beach in 2006 (*pers. comm*. N. Duke) (Fig. 5).

Additional Observations

The authors visited the Jack Barnes Boardwalk on 31 May 2021 accompanied by NAQS botanists to confirm the identity of mangrove species defoliated by *L. lunata*. No live larvae or pupae were observed, but damage to foliage, silk webbing, remains of egg masses, and numerous pupal and larval exuviae were noted on *Ceriops* (Fig. 6). While herbivory was not quantified, observations of *Ceriops* along the Boardwalk indicated highly variable levels of damage, with some plants exhibiting only minor damage to terminal leaves and other plants showing greater than 50% leaf loss (Figs 7, 8). There are at least eleven species of mangrove present in the area, some of which are accessible from the Boardwalk. *Rhizophora stylosa*, and a species of *Bruguiera* (both Rhizophoraceae) have been used as a food plants by *L. lunata* as evidenced by feeding damage on leaves and numerous empty pupae on leaves and trunks. Grey mangrove *Avicennia marina* (Forssk.) Vierh. (Acanthaceae) has been suggested as a possible host by other authors (Pogue and Schaefer, 2007). *A. marina* is present in low numbers in the mangrove community along the Boardwalk; no damage was evident to leaves, although a pupal exuvium was located on the trunk of one tree. Cannonball mangrove *Xylocarpus granatum* K.D.Koenig (Meliaceae) present along creeks in the mangrove area was not utilised.

Discussion

The lunata tussock moth, *Lymantria lunata* is distributed from India throughout Southeast Asia, including New Guinea, Indonesia, the Philippines, to the northern coast of Australia (Pogue and Schaefer 2007). Aggregated museum records of this species indicate an Australian distribution from Cooktown south to Mackay in Queensland (Atlas of Living Australia 2021).

Figs 3, 4. Larva and pupae of *Lymantria lunata*. (3) Late instars on trunk of *Ceriops* sp., Jack Barnes Memorial Boardwalk, Cairns, Queensland. Photo: R. Donnan, 2021. (4) Late instar on the trunk of *Bruguiera parviflora* from Pioneer Estuary, Mackay, Queensland. Photo: Norm Duke, 2021.

Biology and Host Preferences

The biology of *L. lunata* in Australia is relatively undocumented except for Corbet (1963), who recorded details of an eruptive event in Cairns, where moths were attracted to electric lights in such numbers that "Some of the electric light standards looked white at the top, gradually vignetting to a mottled grey towards the bottom (due to egg mass deposition)". Early fears that ornamental trees and garden plots in Cairns would suffer from an infestation of larvae were not substantiated, and despite providing larvae in containers with leaves from many different plant species they did not survive. Eventually Corbet found larvae were developing on *Mangifera indica* (flowers only) and the leaves of *Buchanania arborescens* (as *B. muelleri*), *Semecarpus australiensis* (both Anacardiaceae) and *Ficus benjamina* (Moraceae).

The Philippines population of *L. lunata* seems to be significantly more polyphagous than the Australia population. Larvae have been found feeding on the leaves of *Citrus* (Rutaceae), *Syzygium samarangense*, *S. cumini* (Myrtaceae), *Terminalia*

sp. (Combretaceae), *Ricinus* sp. (Euphorbiaceae), *Diosporos* sp. (Ebenaceae), papaya *Carica papaya* (Caricaceae), *Casuarina equisetifolia* (Casuarinaceae), balsa *Ochroma pyramidale* (Malvaceae), carambola *Averrhoa carambola* (Oxalidaceae), tamarind *Tamarindus indica, Sesbania* sp. (Fabaceae), eggplant *Solanum melongena* (Solanaceae), santol *Sandoricum koetjape* (Meliaceae), guava *Psidium guajava* (Myrtaceae), cashew *Anacardium occidentale* and *Spondias purpurea* (both Anacardiaceae) and pomegranate *Punica granatum* (Lythraceae) (Strand, 1923; Baltazar and Salazar, 1979).

Our observations on the coastal distribution of adults during this recent eruptive event, the evidence of significant damage to mangroves, and the absence of any other regional observations or reports of significant damage to fruit trees and ornamental hosts provides strong evidence that mangrove species in the family Rhizophoraceae are the primary host for Queensland populations of *L. lunata*. In addition to our observations, Corbet (1963) noted "… countless thousands of them (larvae) dangling in midair from the branches of the Mangrove Trees along the foreshores." during the 1962 event. Pogue and Schaefer (2007) interpreted this as implying there may be a mangrove host plant "probably *Avicennia marina*", but as mentioned earlier we found scant evidence that this mangrove species is a food plant, and it is more likely that these larvae were on mangroves in the Rhizophoraceae which are significantly more abundant than *A. marina* in these habitats. Robinson *et al.* (2010) list *Rhizophora* sp. and *Ceriops* sp. as host in Papua New Guinea for moths tentatively identified as "*Lymantria lunata?"* with no further details as to the source and date of this information, or if there are museum specimens available for examination.

Taxonomic Status of Australian *L. lunata*

This divergence in host choice between Australia populations and the highly polyphagous Philippine and other southeast Asian populations of *L. lunata* suggests that the Australian population may be a distinct entity. Specimens from Ingham, Cairns and Cape York (Queensland) were described as a separate species *Lymantria diversa* by Turner (1936) with the male type collected from Ingham. Corbet (1963) notes that *L. diversa* was still in use by local entomologists in the early 1960's, but the genitalia of Australian specimens submitted to entomologists at the Commonwealth Institute of Entomology in London matched those of extralimital specimens of *L. lunata.* Based on this match the Institute's entomologists considered *L. diversa* to be a synonym of *L. lunata* (Corbet, 1963). Although Corbet does not mention it in his 1963 paper, it was highly likely that the specimens submitted to the Institute were from a series collected by J.G. Brooks who was resident in Cairns at the time. Some of Brooks' specimens from the 1962 outbreak are held in the ANIC, with two of these sampled for CO1 sequences by the Barcode of Life Database consortium as detailed earlier in this paper.

Schintlmeister (2004) retained *diversa* as a subspecific rank for Australian and PNG specimens (*L. lunata diversa)*, along with another three subspecies plus

the nominate race. He noted that the taxonomic status of *diversa* was "doubtful", but in the sense that it may represent a distinct species, as the shape of the valve and tegumen in Australian males differed from those from other known populations of *L. lunata*, and that a pair collected from Australia and held in the Natural History Museum, London were externally different to Moluccan and New Guinean specimens. He was unable to draw further conclusions without additional Australian material for comparison. Ingram (2010) expressed similar opinions that *L. lunata* may represent a species complex based on host choice, response to synthetic sex pheromones and variation in male genitalia. Pogue and Schaefer (2007) considered *L. lunata* to be a single variable species and did not recognise the subspecific rankings listed and described in Schintlmeister (2004), including *L. lunata diversa*, but they only examined specimens from the Philippines and did not include any Australian material.

The figured Philippine specimens and the description in Pogue and Schaefer (2007) differ to the series collected from Cairns in this study. The most obvious and consistent difference is the thickness of the brown postmedial line in the forewing of females, which is thicker overall in the Philippines specimens, and expanded at the rear margin of the forewing so it almost merges with the posterior end of the subterminal line. The postmedial in all Australian female specimens from Cairns increases slightly in thickness as it approaches the rear margin of

Fig. 5. Late instar of *Lymantria lunata* on leaf of *Rhizophora stylosa* from Airlie Beach, Queensland. Photo: Norm Duke, 2006.

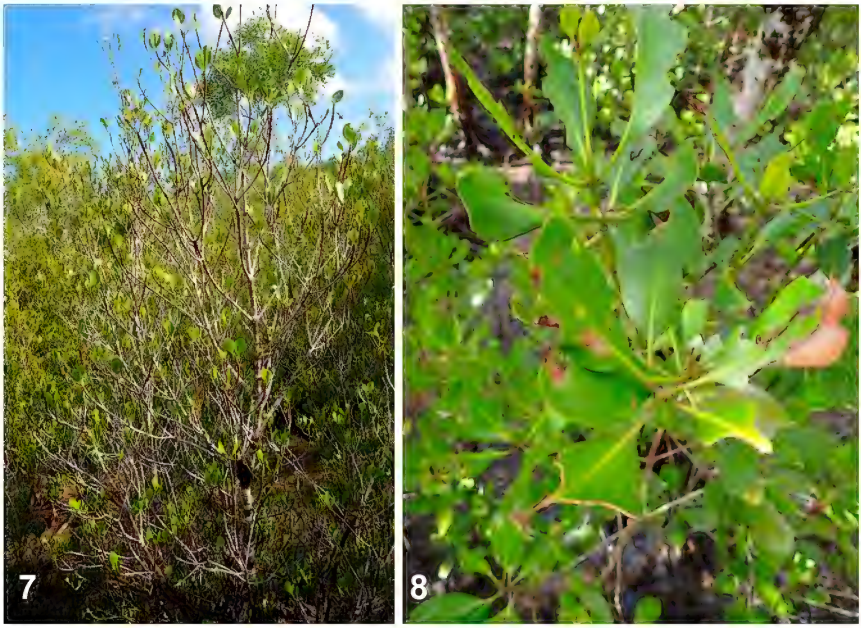
Fig. 6. Empty pupae of *Lymantria lunata* on trunk of *Ceriops* sp., Jack Barnes Memorial Boardwalk, Cairns, Queensland, 31 May 2021.

the forewing but remains subparallel with the subterminal line. Males collected in this study are much darker and more strongly marked in the forewing than the Philippines males figured in Strand (1923), Pogue and Schaefer (2007) and Schintlmeister (2004), with more extensive red markings on the abdomen and posterior base of the hindwing. They most closely resemble the holotype of *L. lunata ingrami* Schintlmeister, 2004 from Irian Jaya (West Papua) figured in Schintlmeister (2004), although the specimens of *L. lunata diversa* figured in the same paper have no reddish or pinkish scales which is not the case for the Cairns specimens in this study. Both *L. lunata ingrami* and the specimens in this study have conspicuous red scaling on the abdomen and posterior base of the hindwing. Schintlmeister (2004) notes that the figured male of *L. lunata diversa* has had its abdomen replaced with that of a completely unrelated moth, and that he did not examine the holotype of *L. diversa*. The fore and hindwing patterns of the Ingham holotype of *L. diversa* matches males collected from Cairns in this study, although it is considerably faded overall, and the red scaling on the abdomen and base of hindwings is not apparent. The male genitalia of Cairns specimens (Horak *et al*., 2020 and this study) and those figured from the Philippines and Indonesia (Schintlmeister, 2004) do not appear to be significantly different.

It has not been possible to locate CO1 sequences for *L. lunata* specimens from regions outside of Australia. Obtaining sequences from populations outside of Australia and Papua New Guinea could provide additional insight into the taxonomic status of the Australian population.

A cautionary note on recent misidentifications of *L. lunata* and *L. antennata*

Some male specimens of *L. antennata* in museum collections and used in publications have been misidentified as *L. lunata* due to a highly uncharacteristic error in the otherwise authoritative book "Moths of Australia" (Common, 1990). The image of *L. antennata* in Plate 19 is erroneously captioned as "*L. lunata*". This error has been noted elsewhere in the grey literature (Ingram, 2010). Caution should be used when interrogating collection databases and interpreting publications on regional *Lymantria*. *Lymantria lunata* records aggregated in the ALA at the time of writing this article have a record of *L. lunata* from the Northern Territory which is based on a specimen of *L. antennata* held in the Australian Museum (Registration K.264559 misidentified by the lead author of this paper) (Atlas of Living Australia, 2021). Male specimens of *L. antennata* collected at pheromone traps in SE Queensland in the early 2000s were also misidentified by the lead author as "*L. lunata*". Tissue from *L. antennata* specimens incorrectly identified as "*L. lunata*" was used in a study investigating DNA barcodes for tussock moths (Ball and Armstrong, 2006) (Genbank accession numbers DQ149570, DQ149571, DQ149572), and the CO1 sequences from that study were then included in a molecular study on the phylogeny of Indonesian *Lymantria* (Sutrisno 2014), which not unsurprisingly got a 100% match between sequences of "*L. lunata*" and *L. antennata*. deWaard *et al.* (2010) used the same sequence data from Ball and Armstrong (2006), but correctly



Figs 7, 8. *Ceriops* sp. (7) with extensive feeding damage, Jack Barnes Memorial Boardwalk, Cairns, Queensland, 31 May 2021; (8) with typical feeding damage, Jack Barnes Memorial Boardwalk, Cairns, Queensland, 31 May 2021.

identified the source specimens in their supporting information as *L. antennata*. The taxonomy for these three sequences has been corrected to *L. antennata* in BOLD (BIN: BOLD:AAA8625, accessed 12 August 2021) but the sequences are still incorrectly included under *L. lunata* in Genbank (accessed 12 August 2021).

Pest Status and Biosecurity Concerns

The pest status of the Australian population of *L. lunata* does not appear to be significant if outbreak populations are infrequent and are only in mangrove communities.

Urtication of humans by this species has been noted by Corbet (1963) and Baltazar and Salazar (1979), by the authors of this current study, and by mangrove researchers (N. Duke *pers. comm.*). Corbet (1963) noted that *L. lunata* confined in a large container overnight with *Papilio* spp. larvae resulted in the death of these *Papilio* although the reasons for this was not clear. The likelihood of contact with late instar larvae in their mangrove habitat is minimal, however the risk of urtication of humans and pets and the ingestion of small larvae should be considered as a public health hazard if subsequent outbreaks occur.

The proximity of mangroves to Yorkeys Knob and Trinity Beach may have contributed to the large number of adults seen at lights in those areas. Fig. 9 is a

map showing mangrove habitats in relation to these locations (map of mangrove habitats *pers. comm.* Jock Mackenzie and Norm Duke, 2021). While it was not possible to access the mangroves at these two locations observations at the Jack Barnes Boardwalk habitat indicated that mangroves may produce significant numbers of moths without suffering debilitating defoliation. An outbreak of *L. lunata* could have a negative impact on mangrove communities if other environmental stresses are present, but even the more heavily defoliated trees near the Boardwalk looked as if they would recover in the absence of continued herbivory. Clusters of empty cocoons of braconid wasps were observed around dead late instar larvae on *Ceriops* leaves at the Boardwalk location, but otherwise the role of parasitoids and predators in suppressing moth populations is not known.

Herbivory on mangroves, and particularly on *Rhizophora* species is thought to be typically low, with less than 10% of leaf area removed, however Duke (2002) noted that large numbers of a native slug moth *Doratifera stenora* Turner, 1902 (Limacodidae) (incorrectly spelt as "*Doratifera stenosa*") were removing up to 30–40% of leaf area of *Rhizophora stylosa* growing at Port Curtis, Central Queensland. The mangroves appeared to be able to sustain this high level of herbivory. Duke (2002) hypothesised that the larval cohorts of *D. stenora* move between trees before serious or fatal defoliation of the plants occurs, and that this behaviour has evolved to prevent over-grazing and ensure sustainability of food resources. Future observations and research may determine if similar adaptations and behaviours occur in *L. lunata*.

Lymantria lunata has been considered a species of quarantine concern for tropical areas outside of its natural distribution, because of the previously observed outbreak population as documented by Corbet, the diversity of recorded host plants which includes cultivated fruit trees, and the potential public health issues due to urticating larval hairs (Pogue and Schaefer, 2007). Given the apparent limited host preferences of Australian populations of *L. lunata*, the risks of this species establishing as a pest in new areas outside of Australia may be overstated, however this does raise the issue that populations of *L. lunata* from elsewhere in SE Asia and particularly from the Philippines may be a biosecurity threat to Australia (Ingram, 2010).

Lymantria lunata egg masses on international shipping containers, cargo and ship structures could easily be confused with other biosecurity threats for Australia and trading partners, such as egg masses from *Lymantria dispar asiatica* Vnukowskij, 1926 and other exotic *Lymantria* species, leading to misplaced effort in diagnostics and potentially costly delays in shipping and cargo movements.

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Thanks to Dawul Wuru Aboriginal Corporation for allowing us access to their land where the observations took place. We are also grateful to the Cairns and Far North Environment Centre for their interest in the project and to the

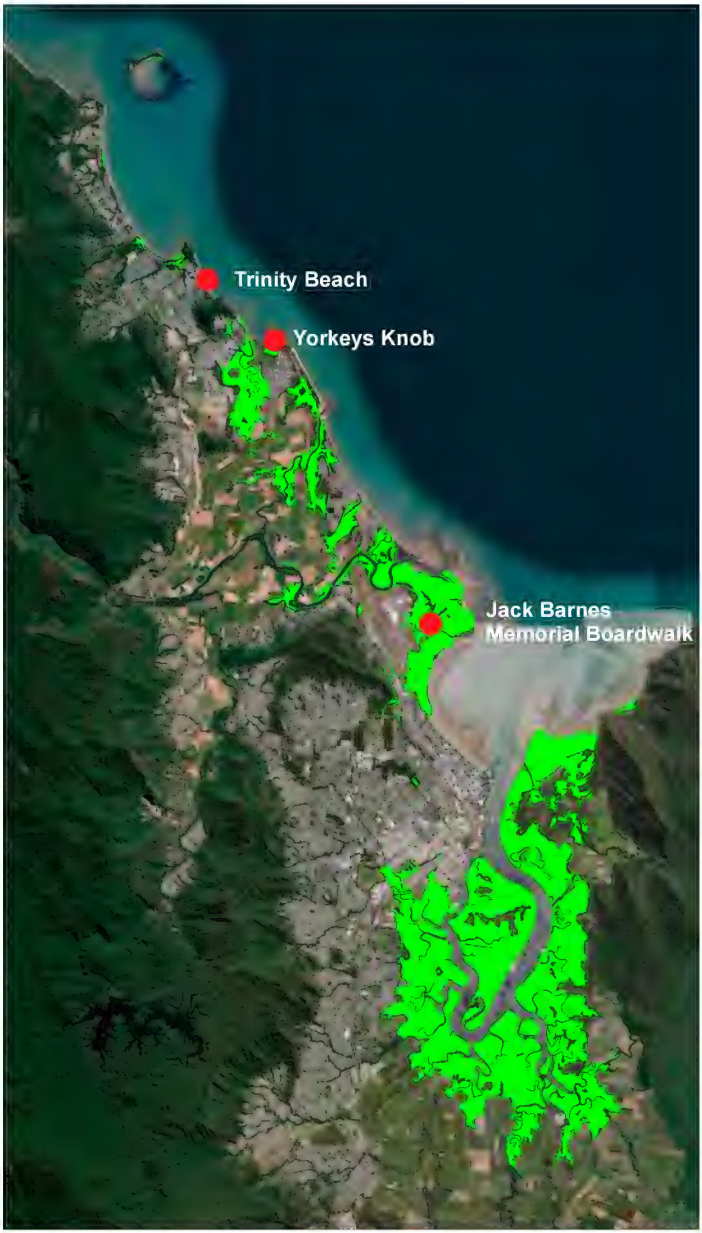

Fig. 9. Distribution of mangrove habitat in the Cairns region (bright green) with known localities of *Lymantria lunata*. Mangrove distribution map sourced from https://qldspatial.information.qld.gov.au/catalogue/ (*pers.comm*. Jock Mckenzie and Norm Duke).

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CONFIRMATION OF THE SYNONYMY OF *LEIOPROCTUS NIGRIVENTRIS* (FRIESE, 1924) AND *LEIOPROCTUS THORNLEIGHENSIS* (COCKERELL, 1906) (HYMENOPTERA: COLLETIDAE)

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Abstract

The taxon *Leioproctus nigriventris* (Friese) has been treated both as a valid species and as a synonym of *Leioproctus thornleighensis* (Cockerell). Both are treated as valid species in the most recent revision (Maynard, 2013). Re-examination of the type material has confirmed that *L. nigriventris* is a junior synonym of *L. thornleighensis*. *Leioproctus capillatus* (Rayment) remains the only currently identified Australian *Leioproctus* Smith species with long setae on the compound eyes. A lectotype of *L. thornleighensis* is designated.

Keywords: solitary bees, taxonomy, Australia

Introduction

In his exhaustive revision of Australian bee genera, Michener (1965) listed the species in each genus, explicitly ignoring any synonymy previously proposed "since published synonymy is subjective and often wrong". It was his hope that future scholars when revising a genus would reassess the evidence.

Cockerell (1929) synonymised *Lamprocolletes nigriventris* Friese, 1924 with *Paracolletes thornleighensis* Cockerell, 1906. A checklist of Australian Neopasiphaeinae (Almeida, 2008) assumed Cockerell's synonymy was correct, but presented no argument to support the decision. Maynard's (2013) revision of seven subgenera of *Leioproctus* Smith, 1853 treated both as valid species, without addressing Cockerell's decision. The Australian Faunal Directory, which is used as the definitive checklist of Australian bees, follows Maynard's revision.

The original description of *L. nigriventris* was of the male and only mentions several males collected at Thornleigh in September 1906 (Friese, 1924). Yet, a few years later, when Cockerell examined the material he found a female specimen also labelled as caught in September 1906 that had been identified by Friese as conspecific. Cockerell concurred with the assignment, but was astonished to find that the eyes of the female had sparse setae that reminded him of *Trichocolletes* Cockerell, 1912. Michener (1965), in his notes on species wrote "in a few [*Leioproctus*] species the eyes are hairy. This is true of *nigriventris*

Figs 1, 2. *Leioproctus thornleighensis* dorsal view: (1) female; (2) male.

Friese, a very ordinary-appearing species usually identified as *thornleighensis* (the type of *thornleighensis* has bare eyes)", which statement is open to more than one interpretation.

One well-documented *Leioproctus* species that does have hairy eyes in both sexes is *L. capillatus* (Rayment, 1935).

The type material for *L. thornleighensis* consists of two male syntypes in the Natural History Museum, London.

Methods

Type material was re-examined for *L. nigriventris* by CSS and JGR, *L. thornleighensis* by JM and *L. capillatus* by MB. Specimen images were exchanged to supplement those available from the NHM Portal (Scott and Smith, 2014). The following abbreviations are used for collections in which the specimens are lodged: AMSA, Australian Museum, Sydney; AMNH, American Museum of Natural History, New York; ANIC, Australian National Insect Collection, Canberra; NHML, Natural History Museum, London.

Taxonomy

Leioproctus thornleighensis (Cockerell, 1906)

(Figs 1–9)

Paracolletes thornleighensis Cockerell, 1906: 27.

Lamprocolletes nigriventris Friese, 1924. — Cockerell, 1929: 1 (synonym); Cardale, 1993: 36 (synonym); Almeida, 2008: 11 (synonym).

Figs 3–6. Male *Leioproctus thornleighensis*: (3) face; (4) metasoma, dorsal view; (5) lateral view; (6) ventral view (partial).

Leioproctus (Leioproctus) thornleighensis (Cockerell). — Michener, 1965: 52 (new genus); Maynard, 2013: 25.

Identification of *Leioproctus thornleighensis*

Specimens believed to be *L. thornleighensis* have been collected in the Sydney area on ten separate occasions. The males agree with Cockerell's original description, but as noted by Michener, the species is not particularly distinctive. In order to confirm the identification, photographs of males from the AMSA collection (Fig. 2) were prepared to illustrate (1) the dense facial hair that largely obscures dense punctures on the clypeus (Fig. 3); (2) the polished metapostnotum; (3) the close, deep, medium punctures of the metasomal terga and the depressed, brown tergal margins (Fig. 4); (4) the distinct apical fringe on the fifth metasomal sternum (Fig. 6); (5) the sculpture of the frons, which is punctured with interspaces smooth, not striolate or roughened; (6) the length of the flagellum, which is *ca* 1.15× head width; (7) the close covering of short erect finely-branched setae on the metasoma, visible when viewed laterally (Fig. 5);

and (8) the jugal lobe of the hind wing which almost reaches cu-a. While none of these is uniquely distinctive, the combination of strong punctures with the other characteristics is not present in other described species of the genus. The male terminalia (Figs 7–9), could be compared only with Cockerell's original description, which is rather unclear, but mentions a dark object "something like the head of a nail with a slender stem". The apical process of S8 matches that description and the shape is unusual in *Leioproctus.*

The photographs were compared by JM with specimen Hym.17.a.432 in NHML and found to agree with the criteria described above. The same photographs then were used for comparisons with specimens in AMNH.

As reported in the original description, the NHML has two specimens bearing the words Thornleigh Froggatt. 1890–91, and the collector's number 32. In addition there is a label in Cockerell's hand stating Paracolletes thornleighensis, Ckll, TYPE. In the absence of further designation by the author, both are syntypes. In order to clarify their status, we here designate the specimen bearing the museum identifier B.M. TYPE as the lectotype of *Leioproctus thornleighensis* (Cockerell, 1906) and a new label has been attached. The second specimen has been labelled as a paralectotype.

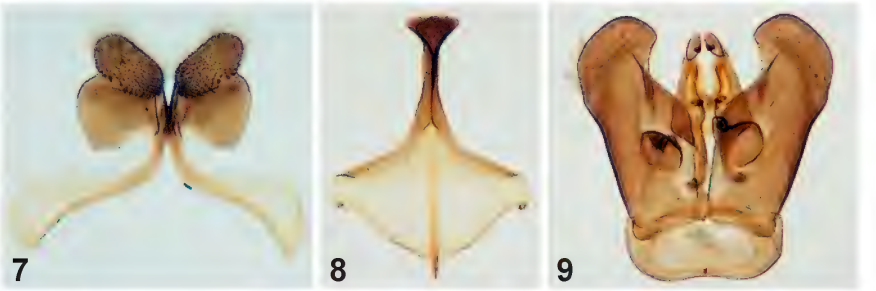
Identification of the type of *L. nigriventris*

The AMNH collection has one male and one female specimen labelled as *Lamprocolletes nigriventris* with Friese type labels and date and location labels corresponding to those reported in the original description (Friese, 1924). The female specimen carries an additional label indicating an undated re-identification by Cockerell as *Paracolletes thornleighensis* (Fig. 13). From the original description, the male is either the name-bearing type or a syntype from the type series (Fig. 14).

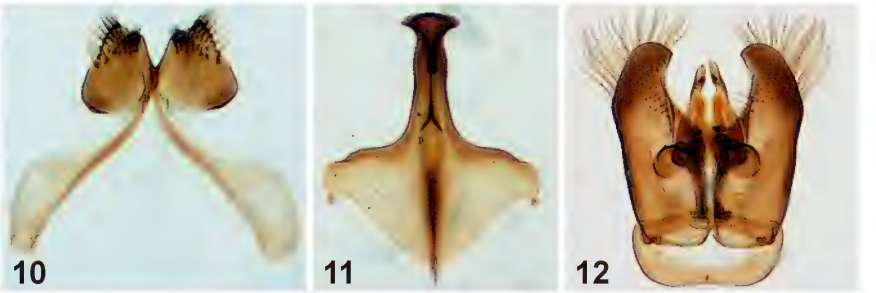
The male type of *L. nigriventris* does not have long setae on the compound eye and, though in less than perfect condition, was consistent with the same set of photographs that matched the lectotype of *L. thornleighensis.* Additional confirmation was provided by the apex of hidden sternum S8 which was protruding sufficiently that the unusual shape, "like the head of a nail" was visible. This confirms Cockerell's decision that the name *L. nigriventris* is a junior synonym of *L. thornleighensis.*

The female identified by both Friese and Cockerell as *L. nigriventris* is clearly not conspecific. She has sparse long setae on the compound eyes. There have now been numerous collections of *L. thornleighensis* (Batley, 2019) and in five instances females were collected with males in the absence of any other *Leioproctus* species. The female of *L. thornleighensis,* like the male, has at most inconspicuous short setae on the compound eye.

The only reported Australian *Leioproctus* species with long setae on the eyes is *L. capillatus,* in which both sexes have hairy eyes. The sexes were associated through a pair taken *in copula* (Rayment, 1935). Friese's female is presumably



Figs 7–9. Ventral views of male terminalia for *Leioproctus thornleighensis*: (7) S7; (8) S8; (9) genital capsule.



Figs 10–12. Ventral views of male terminalia for *Leioproctus capillatus*: (4) S7; (5) S8; (6) genital capsule.

Figs. 13, 14. Labels from *Lamprocolletes nigriventris* specimens in AMNH: (13) female; (14) male.

L. capillatus and has the following characteristics consistent with that assignment: eyes with long setae; length *ca* 10.5 mm; clypeus densely punctate; scutum polished with open to sparse punctures medially, close laterally; metapostnotum polished; metasoma black, shining with dense punctures; hair of hind tibial scopa mostly black; hind tibial spur pectinate with about eight teeth whose length is slightly greater than the basal width of the spur.

Identification of the female is of no taxonomic significance and is of interest only for reconstructing the events contributing to earlier decisions.

Notes on behaviour of *L. thornleighensis*

Paradoxically, when *L. thornleighensis* has been collected in the Sydney region, it has been locally abundant (MB, *pers. obs.*), yet few records appear in Atlas of Living Australia (ALA, 2021). It is unclear whether this is because the species has not been collected or because the species has not been recognised in museums. Although mentioned in a partial revision of *Leioproctus* (Maynard, 2013), it did not fall within any of the new subgenera or species groups, so did not appear in any key.

One possible explanation may be that it is infrequently collected because of a preference for an inconspicuous flower. All collections of *Leioproctus thornleighensis* in the Sydney area have been from *Polyscias sambucifolia* (Sieber *ex* DC.) Harms apart from 2 specimens taken from *Leptospermum* in the near vicinity of flowering *Polyscias* (Batley, 2019). Unlike *Leioproctus launcestonensis* (Cockerell, 1914), which visits *Polyscias* and other flowers, it has not been seen on other plants or collected before early December, when *Polyscias sambucifolia* comes into bloom.

The flower is common and widespread from Queensland to Victoria and Tasmania (AVH, 2021) and a survey across this distribution could provide a better understanding of the abundance of *L. thornleighensis*. A brief survey of selected sites across the Sydney metropolitan area found the bee everywhere that *Polyscias* was flowering (MB, *pers. obs.*)

Discussion

The uncertainty that prompted the current re-investigation was the cumulative result of several decisions that were, for the most part, reasonable in isolation. Michener's assessment that early decisions about synonymy should be reviewed was justified. Although Cockerell's decision was correct in the present case, it was incorrect for *Amegilla alpha* (Cockerell, 1904) (Leijs *et al.*, 2017). Equally, apart from the hairy eyes and male terminalia (Figs 7–9, 10–12), there are superficial similarities between *L. thornleighensis* and *L. capillatus*, so that in the absence of both sexes of each it was not unreasonable to propose that the hair was sex-linked. Modern labelling practice had not been formalised by 1929 and the application of more than one type label by Friese is a common occurrence that needs to be accommodated when dealing with older type material. It is also

likely that Cockerell viewed his decision concerning synonymy as applying to the species, not to a name-bearing type, which might explain the identification label on the female specimen.

There were, however, some errors and small oversights. The collection date on the label attached to the male *Lamprocolletes nigriventris* specimen is inconsistent with active period for *L. thornleighensis*. Friese is known to have used pre-printed determination labels often leading to incorrect dates (Rasmussen and Ascher, 2008). The dotted-line borders on the labels with collection information (Fig. 14) suggest that those labels were prepared by Friese and not the original collector. Furthermore, the label gives the location simply as Sydney, whereas the description specifies Thornleigh without mentioning Sydney.

Michener's slightly confusing reference to *L. nigriventris* as a species with hairy eyes makes more sense if we assume he noted Cockerell's re-identification label, but overlooked which sex was described by Friese.

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FIRST DESCRIPTION OF A MALE *CASTIARINA INSCULPTA* (CARTER, 1934) (COLEOPTERA: BUPRESTIDAE), A THREATENED TASMANIAN JEWEL BEETLE

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Abstract

Current knowledge of *Castiarina insculpta* (Carter) in Tasmania is reviewed, and the adult male and its genitalia are described and illustrated.

Keywords: Tasmanian Central Highlands, aedeagus, Miena Jewel Beetle

Introduction

Castiarina insculpta (Carter, 1934) was originally collected in the *yingina*/Great Lake region of Tasmania by Critchley Parker in 1934. It was formally described in that year (Carter, 1934) based on the single female specimen obtained. By 2010, six dead female *C. insculpta* specimens were recognized, but it was not until 2013 that multiple live *C. insculpta* were discovered and a substantial increase in knowledge of the species' biology ensued (Bonham *et al.* 2013, Spencer and Richards 2014, Richards and Spencer 2016, 2017, 2020).

Twenty described species of *Castiarina* Gory and Laporte, 1838 occur in Tasmania, although four are unlikely to be permanent residents. Seven species are endemic to the state and three are purported to be rare (Cowie 2001). Two of the endemic species, *C. insculpta* and *C. virginea* (Erichson, 1842), belong to the *C. rectifasciata* species group which Barker (2006) founded on structural similarities. They are readily separated from each other by the angle of the marginal elytral spines, and other characters. *Castiarina insculpta* was listed as extinct under the Tasmanian *Threatened Species Protection Act* 1995, but further specimens discovered in the mid 2000's led to a review of its status. In 2008 the species was down-listed to endangered (Threatened Species Section 2021).

Several suspected male *C. insculpta* specimens were collected by the authors between 2013 and 2020, plus three definite males, each with their aedeagus everted. The confirmed males come from two locations in Tasmania's Central Highlands. They comprise two drowned specimens recovered from Lake Ada in January 2017, and one specimen found in the Lake Augusta sand dunes in January 2019. This paper provides the first description and images of a male specimen and aedeagus of *C. insculpta*.

Abbreviations

KRCPS, joint collection of Karen Richards and Chris P. Spencer, Moonah, Tasmania (to be deposited in TMAG in near future); NHM, Natural History Museum, London; TMAG, Tasmanian Museum and Art Gallery, Hobart, Tasmania.

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* Deceased

Figs 1, 2. *Castiarina insculpta*. (1) male; (2) aedegus.

Castiarina insculpta (Carter, 1934)

(Figs 1, 2)

Stigmodera (*Castiarina*) *insculpta* Carter, 1934: 255.

Type material. *Holotype* ♀, AUSTRALIA, Tasmania, Great Lake, 1934, Critchley Parker (NHM).

Additional specimens. 1♂, Tasmania, Lake Augusta, 2019, Chris P. Spencer (TMAG Registration No. F 127265); 1♂, Lake Ada (41°52.977'S 146°28.395'E) January 2017 (KRCPS); 1♂, Lake Augusta sand dunes (41°51.964'S 146°31.148'E) January 2019 (KRCPS). Additional male and female measurements were recorded from Tasmania, Liawenee (41°53.939'S 146°40.267'E) in February 2021.

Description of male. Measurements in mm: length, 11.0 (11–11.8, mean = 11.52), width, 4.0 (4.0–4.6, mean = 4.39) mm, (n = 14).

Colour (Fig. 1): Head, pronotum and scutellum metallic green, antennae bronze-black, mouthparts black. Elytra metallic green with paired yellow markings, basal fascia rounded medially narrowing anteriorly, small yellow patch on humeral callus extending along lateral margin, rounded medial patch, post-

medial fascia narrowing to and extending along lateral margin. Ventral surface metallic green. Legs femora and tibiae metallic green, tarsi bronze-black, setae silver. Overall colour varies between specimens, ranges from bright metallic blue to bright metallic green while the yellow markings vary in shape, size, intensity and coalescence; tarsi vary in colour from bronze-black to metallic green.

Shape and sculpture: Head punctured, median sulcus present, mouthparts short. Antennomeres 1–3 obconic, 4–11 triangular. Pronotum heavily punctured with shallow foveae, apical margin projecting medially, basal margin bisinuate, without basal notch, lateral margin parallel-sided at base, angled outwards then rounded to widest medially, rounded and narrowed to apex. Scutellum scutiform, flat, without punctures. Elytra striate-punctate, punctures regular and well defined, ridges carinate, 1 to 4 close, 5 and 6 further apart and more strongly raised, apex bispinose, marginal spine pointing inwards, sutural spine reduced, margin between spines deeply concave. Ventral surface finely punctured, mesosternal process flat. S7 truncate.

Aedeagus (Fig. 2): brown-testaceous, elongate, slightly expanding outwards from basal piece. Parameres rounded at apex. Penis with acute apex, sharp, sides strongly concave. Apophysis of basal piece moderately wide, rounded at apex.

Description of female: Measurements: holotype ♀, length 12.0, width 4.5 mm. Additional ♀♀: length (11.2–12.2, mean = 11.66), width (4.2–4.7, mean = 4.52) mm, ($n = 5$).

Colour: as for male.

Shape and sculpture: similar to male, but slightly broader. S7 truncate, row of prominent sensory bristles along hind margin present.

Discussion

The drowned specimens from Lake Ada were disarticulated on discovery and only their aedeagi were retained.

Barker (2006) included *C. insculpta* in the *rectifasciata* group, and while there are some morphological similarities with the overall aedeagal shape of other group members, the closest being *C. rectifasciata* (Saunders, 1868), only two the seven species occur in Tasmania, the second being *C. virginea*, the aedeagus of which is quite dissimilar. As with many Tasmanian buprestid species, the colour and markings of *C. insculpta* display plasticity in both sexes. Coalescence of fascia was observed on several *C. insculpta* specimens and appeared to be location-specific. Subsequent visits to this area confirm this to be a site-specific variation. Given the threatened status of the species, the location is withheld to protect against illegal targeted collection.

Pre-adult stages are confined to scaly everlasting bush, *Ozothamnus hookeri* Sonder (Asteraceae) which is also the main food plant for adults, although they sometimes feed on blossoms of alpine heath-myrtle, *Baeckea gunniana* Schauer (Myrtaceae) (Richards and Spencer 2016, 2017).

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A NEW GENUS OF ERIOCOCCIDAE (HEMIPTERA: COCCOMORPHA) FOR AN UNUSUAL SPECIES ON *LEPTOSPERMUM* (MYRTACEAE)

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Abstract

A new genus, *Fimbriaticoccus* Gullan and Williams **gen. n.**, is erected for the scale insect *Ripersia leptospermi* Maskell (Hemiptera: Coccomorpha: Eriococcidae). *Fimbriaticoccus leptospermi* (Maskell) **comb. n.** is a rare species, known only from two collections in South Australia and one in New South Wales, and it has unusual morphology. The adult female most closely resembles the adult females of the atypical eriococcid genus *Sangicoccus* Reyne, and also the mealybug genus *Rastrococcus* Ferris (Pseudococcidae), with which it has been confused. Redescriptions are provided for the adult female, second-instar female and first-instar nymph of *F. leptospermi*, and taxonomic illustrations are provided for the adult female and first-instar nymph. Diagnostic notes are provided on the adult male. The morphology and probable relationships of *Fimbriaticoccus* are discussed. It appears to be host-specific to *Leptospermum* (Myrtaceae).

Key words: scale insect, eriococcid, *Fimbriaticoccus*, *Ripersia*, *Sangicoccus*

Introduction

William Miles Maskell was an early authority on scale insects, publishing on them from 1879 until his death in 1898, and although based in New Zealand for his career, he was sent specimens from a number of countries including Australia (Myers 1922; Deitz and Tocker 1980; Morales 1993). In 1889, Maskell described a remarkable scale insect from South Australia as *Ripersia leptospermi*. He provided sketches of the morphology of the adult female and the first-instar nymph, and described the live adult female as having a marginal fringe composed of tufts of long, white, curling filaments (Fig. 1) that formed a kind of bower covering a mass of more granular wax in which eggs were laid. The long filaments emanated from clusters of what Maskell called "projecting tubular spinnerets". The live adult female was described as dark purple in colour and producing a rich red dye when immersed in potassium hydroxide (used to dissolve the body contents prior to mounting on microscope slides). Maskell's name for this species implies that the specimens were collected from *Leptospermum* (Myrtaceae). Although Williams (1985a) and thus ScaleNet (García Morales *et al*. 2019) recorded the host plant of the original collection as *Leptospermum laevigatum* (Gaertn.) F. Muell., Maskell (1889) made no mention of either the host plant or the collection locality in his paper. Maskell received his original specimens of *R. leptospermi* from Mr F.S. Crawford of Adelaide, South Australia, but the specific localities are not stated for any of the six species of scale insect described in Maskell's (1889) publication.

A few years after the original description of *R. leptospermi*, Maskell received further material of this species collected in 1892 from *Leptospermum* sp. and

sent by Mr Albert Koebele from Sydney (Maskell 1893). Maskell used these specimens to provide brief descriptions of the pupal and adult male and what he believed to be the second-instar female of *R. leptospermi*.

Although Maskell (1889, 1893) considered *R. leptospermi* to belong to the Dactylopiidae, the latter family group was poorly defined at that time and included many species now placed in different families (Williams and Ben-Dov 2015). Williams (1985a) in his book on Australian mealybugs, transferred *R. leptospermi* to the Eriococcidae after examination of Maskell material deposited in the United States National Museum of Natural History (USNM). However, Maskell's species remains in *Ripersia* Signoret, 1875b, which is a mealybug genus (Pseudococcidae), now recognised only for the type species *R. corynephori* Signoret, 1875b, collected in France, and for *R. leptospermi* (García Morales *et al*. 2019). Other species previously placed in *Ripersia* were transferred to other mealybug genera or synonymised (Matile-Ferrero and Ben-Dov 1995). Signoret's original material of *R. corynephori* is believed to be lost and a subsequent redescription by Reyne (1951) was not based on type material, as discussed by Ben-Dov and Matile-Ferrero (1995). The latter authors concluded that *R. corynephori* was an unrecognisable taxon, but *Ripersia* and its type species *R. corynephori* were retained as unrecognisable taxa within the Pseudococcidae (Matile-Ferrero and Ben-Dov 1995). It is highly unlikely that *R. corynephori* and *R. leptospermi* are congeneric, even if it could be determined that both species belonged to the same family, given their extreme geographic separation and their very different host plants. *Ripersia corynephorus* was collected from a grass (Poaceae), whereas *R. leptospermi* was from a woody shrub (Myrtaceae).

Most of Maskell's specimens of *R. leptospermi* are housed now in the New Zealand Arthropod Collection in Auckland. After Maskell's death, his personal collection was acquired by the New Zealand Department of Agriculture in Wellington, which in 1906 approved a request by the Bureau of Entomology of the United States Department of Agriculture in Washington, D.C., for the loan of the Maskell collection, with the loan consignments sent in 1908 and 1909 (Morrison and Morrison 1922; MacGillivray 1923; Deitz and Tocker 1980). While Maskell's collection was in Washington, some dry specimens of *R. leptospermi* were mounted on microscope slides and retained there. In addition to Maskell's specimens of *R. leptospermi*, we identified a more recent collection made by the late H.M. Brookes at Hartley, about 50 km SE of Adelaide in South Australia. The latter were almost certainly from the leaves of *Leptospermum*, as recorded on Brookes' specimen index card for the collection, but not on the slide labels. Brookes also collected mealybugs on *Melaleuca uncinata* R. Br. at the same locality on the same day and these specimens later became part of the type series used by Williams (1985a) to describe *Rastrococcus melaleucae* Williams, 1985a (Pseudococcidae). Brookes' specimen index card for the collection of *R. leptospermi* from *Leptospermum* incorrectly records the insect species as *R. melaleucae*, probably because the adult females of *R. leptospermi* superficially

resemble adult females of *Rastrococcus* Ferris, 1954 due to the distinctive marginal clusters of truncate setae found on both species.

In early 2019, D.R. Miller examined slide-mounted specimens of *R. leptospermi* from the Maskell material held in the USNM and confirmed the action of Williams (1985a) in transferring this species to the Eriococcidae. Miller reported in ScaleNet (García Morales *et al.* 2019) that the adult females have tubular ducts of the typical eriococcid type with a cup at the inner end; the legs have very few setae; the sensoria [here referred to as campaniform sensilla] on the trochanter are transverse in the middle of the segment rather than near the femur as on most pseudococcids; the multilocular pores have five to nine outer loculi [here almost all pores seen have seven outer loculi] that are star shaped as in most eriococcids; the antennae apparently are six segmented; the labium seems to be three segmented with a narrow basal segment; there are four pairs of anal ring setae; there are cruciform pores [considered here to be bilocular microtubular ducts] on the derm and translucent pores on the hind coxa; there was no evidence of ostioles, a circulus or trilocular pores, which are typical pseudococcid features.

This paper resolves the taxonomic status of *R. leptospermi* by erecting a new genus for its reception. The species is redescribed based on the adult female, second-instar female, first-instar nymph and adult male. Taxonomic illustrations are provided for the adult female and first-instar nymph. The probable relationship of the species with the eriococcid genus *Sangicoccus* Reyne, 1965, and its morphological convergence with certain mealybugs (Pseudococcidae) are discussed.

Materials and methods

There are specimens of *R. leptospermi* in three museum collections based on three collections of this species. Some dry material and four slides of specimens mounted by Maskell are housed in the New Zealand Arthropod Collection (NZAC), Landcare Research, Auckland, New Zealand; additional slides were prepared from the NZAC dry material by PJG for this project. Four slides prepared in the USA in the early 1900s from the Maskell dry material are deposited in the U.S. National Museum of Natural History (USNM), housed at the U.S. Department of Agriculture, Beltsville, Maryland, USA. Slide-mounted specimens of a more recent collection made by the late H.M. Brookes are held in the Australian National Insect Collection (ANIC), CSIRO, Canberra, Australia. Adult females are mounted one to four specimens per slide; with two slides (one NZAC, other USNM) of three females each including one pharate adult female. Nymphs and adult males are mounted from one to several per slide. A slightly modified version of the method of Gullan (1984) was used to prepare microscope slides from dry specimens, with specimens rehydrated prior to clearing in 10% potassium hydroxide, washed in water, stained in an acidified solution of acid fuchsin, and dehydrated through a series of baths of absolute ethanol and absolute propanol, prior to mounting in Canada balsam.

The morphological terms used in the description are explained by Miller and McKenzie (1967) and Williams (1985b). Ventrally there are structures that here are called bilocular microtubular ducts, but are referred to as bilocular pores (Kondo *et al*. 2006) or cruciform pores by some other researchers (e.g., Williams 1985b; Miller and McKenzie 1967; Miller and Miller 1993). The very obvious outer rim gives these structures the appearance of pores but actually they are a kind of microtubular duct because they have an inner tube and filament when viewed under high magnification. In the species description of the adult female, the values for measurements and counts are reported separately for Maskell's and Brookes' specimens if they do not overlap. Such differences may be due to the very different maturity of the adult females from the two collections, with Maskell's specimens being recently eclosed adults. All measurements are maximum dimensions (e.g. body width and femur width were recorded at the widest points) and are expressed as the range. Tarsal length excludes the claw. Spiracle length includes the muscle plate (apodeme). Setal lengths include the setal base. The illustrations of the adult female and first-instar nymph each represent a generalised individual based on several of the specimens used for the description. The central drawing shows the venter on the right and the dorsum on the left. Enlargements around the central drawing are not drawn to the same scale.

Maskell appears to have retained no type material of *R. leptospermi,* although his 1892 collection and that from H.M. Brookes are clearly the same species as that described in 1889. There is no requirement to designate a neotype because the identity of the species is not in doubt (International Commission on Zoological Nomenclature 1999). One adult female mounted by PJG from Maskell dry material belonging to the NZAC has been deposited in the ANIC (with permission). Although we could not designate a lectotype of this Australian species, NZAC follows the principle that primary type material should be deposited in the region of the world from which a species was described, if suitable repositories exist there for the long-term preservation of type specimens (Deitz and Tocker, 1980: 17–18). Here we deposited one non-type specimen in the ANIC in lieu of a lectotype.

We have registered the new genus name published in this paper with the Official Registry of Zoological Nomenclature (ZooBank) and cite the Life Science Identifiers (LSIDs) after the heading for the genus and species names. Each LSID is a globally unique identifier for ZooBank registration entries.

Taxonomy

Fimbriaticoccus Gullan and Williams gen. n.

zoobank.org:act:E755249D-8178-4754-A5FE-2923DD7CC8C5

Type species. *Ripersia leptospermi* Maskell 1899, by monotypy

Generic diagnosis of adult female. *Unmounted specimens.* Body subcircular, dark purple in colour, covered in white mealy wax and with many very long, white,

cottony, curling filaments radiating from margin of entire body. For more detail, refer to description for the type species below. *Slide-mounted specimens.* Body ovoid, more rounded at maturity, up to 1.5 mm long and 1.2 mm wide. Eyespots with a sclerotised centre. Frontal lobes absent. Antennae 6 segmented, with third segment longest. Labium apparently 3 segmented. Legs slender and long relative to body size in younger adults; hind legs with rimmed translucent pores dorsally and ventrally on coxa; tarsal digitules subequal in length and capitate; claw digitules also subequal and capitate, and claw denticle minute to absent. Anal ring with 8 anal ring setae. Anal lobes moderately developed, each with a long apical seta, 2 shorter hair-like setae and 3 truncate spine-like setae. Margin of each side of body with 12 segmental setal clusters (including a cluster on each anal lobe) resembling mealybug cerarii except that locular pores are absent, each cluster with 3–24 truncate spine-like setae, many of which have a few to several microtubular ducts around setal base. Dorsum with sparsely distributed, thick, almost parallel-sided setae each with a rounded apex; a scattering of multilocular pores each with 7 outer loculi; sparse microtubular ducts (in addition to those at base of truncate setae), but no macrotubular ducts. Venter with hair-like setae on all segments; macrotubular ducts each slender and membranous towards opening, with an inner filament and cup, distributed submarginally on each side of abdomen; multilocular pores each with 7 outer loculi (rare pores with 5 or 9 loculi), distributed in submarginal clusters and across abdominal segments; bilocular microtubular ducts in short line or band posterior to each anterior spiracle and sometimes a few near base of one or more pairs of legs.

Etymology. The genus name is formed from the Latin word "fimbriatus" meaning fringed, combined with the name *Coccus* that was the first genus name used for scale insects ("coccum" is Latin for berry or a round insect). The name refers to the marginal fringe of truncate spine-like setae on adult and second-instar females and is of masculine gender.

Fimbriaticoccus leptospermi (Maskell) comb. n.

urn:lsid:zoobank.org:act:5D4B34C4-38F6-4FB2-AEEF-ED60FE317D34

(Figures 1–3)

Ripersia leptospermi Maskell 1889: 106–107, plate XIV, fig. 5a–f.; Maskell 1893: 235, plate XVII, fig. 6; Williams 1985a: 40.

Maskell material examined. AUSTRALIA: South Australia (locality unknown): 1 original Maskell slide with label: "Ripersia / leptospermi / Larva / 1888 W.M.M.", but with 1 first-instar nymph of an unidentified mealybug (NZAC); New South Wales: Sydney, from *Leptospermum* sp., sent to Maskell by Koebele: 1 original Maskell slide with label: "Ripersia / leptospermi / ♀ 2nd stage / 1892 W.M.M.", but with 4 young adult females (NZAC); 10 slides prepared by PJG, 2021, from Maskell dry material in small rectangular pill box with label: "Rip. leptospermi Mask. 86 / Australia" [not in Maskell's handwriting] and 3 triangular pointing cards with "86", 9 young adult females (6 slides), 1 second-instar female (1 slide), 4 exuviae of second-instar females (1 slide), 1 male pupa, affected by fungi (1 slide), and 2 adult males, 1 very poor (1 slide) (all NZAC, except 1 adult

female deposited in ANIC); same collection as previous, Maskell dry material, probably all nymphs, in small cylindrical pill box with lid label: "Ripersia / leptospermi / ♀s and ♂s and / larvae / Australia" (NZAC); same collection as NZAC, but 4 slides prepared in the USA, labels only with "Ripersia / leptospermi / Mask. / Australia / Mask. Coll. No. 86" (NZAC), 5 adult females (1 very poor) and 1 adult female pharate in second-instar cuticle (3 slides), 4 eggs/embryos and 1 recently eclosed first-instar nymph (1 slide) (USNM).

Non-Maskell material examined. AUSTRALIA: South Australia, Hartley, 28.xi.1960, H.M. Brookes, on leaves of *Leptospermum*, Specimen Index No. 96/60 [incorrectly recorded as *Melaleuca* on slide labels, but correct on Brookes' Specimen Index card], 7 adult females (4 slides) and 8 first-instar nymphs (1 slide) (ANIC).

The NZAC also has two additional original Maskell slides (not seen by present authors) with the date 1892 (one slide with an adult male and the other with a second-instar male) with similar labels to the 1892 slide of young adult females (mislabelled as "2nd stage") except for name of instar. The specimens on these three slides are not types because the species was described in 1889. The 1892 collection is undoubtedly that referred to by Maskell (1893), when he described the male pupa and adult male and what he believed was the second-instar female, as being from *Leptospermum* sp. from Sydney, sent by Mr Koebele. Specimens on Maskell's four original slides in NZAC are neither cleared nor stained and thus setae and pores are obscured. Maskell's slide of a first-instar nymph was from the original collection from 1888, but it is a pseudococcid (under oil with x100 objective, a trilocular pore can be seen associated with each of two marginal spine-like setae, but other pores are obscured by body contents); this nymph must have been a contaminant that Maskell accidentally mounted as belonging to his *R. leptospermi*. Similarly, the rectangular box of Maskell dry material in NZAC also had at least two first-instar nymphs of a very different eriococcid genus, which were contaminants.

We believe that the dry specimens in the small cylindrical pillbox and the small rectangular box in NZAC and the slide-mounted specimens in the USNM all belong to the same collection as three of the NZAC original Maskell slides. All female specimens perfectly match Maskell's original description of the very distinctive adult female and one of the NZAC boxes and the USNM slides share the collection number 86. The cylindrical pillbox only has a label on the lid (see above) and appears to contain only dry nymphs (Grace Hall, NZAC, pers. comm.); the mention of males on the lid label implies it is not part of the 1888 collection, which Maskell (1889) stated had no males. Maskell prepared a hand-written ledger of his scale insect specimens, and a copy is stored in the NZAC. It records the following entry for *F. leptospermi*: "86. Ripersia leptospermi Maskell Australia / insects in sitû / Trans. Roy. Soc. South Australia 1887–88 p. 106 / N. Z. Trans. Vol. xxv, p. 235".

Description of adult female.

Unmounted specimens. Not seen by present author(s), but an archival image in the USNM records the appearance of the wax filaments on the female's dorsum

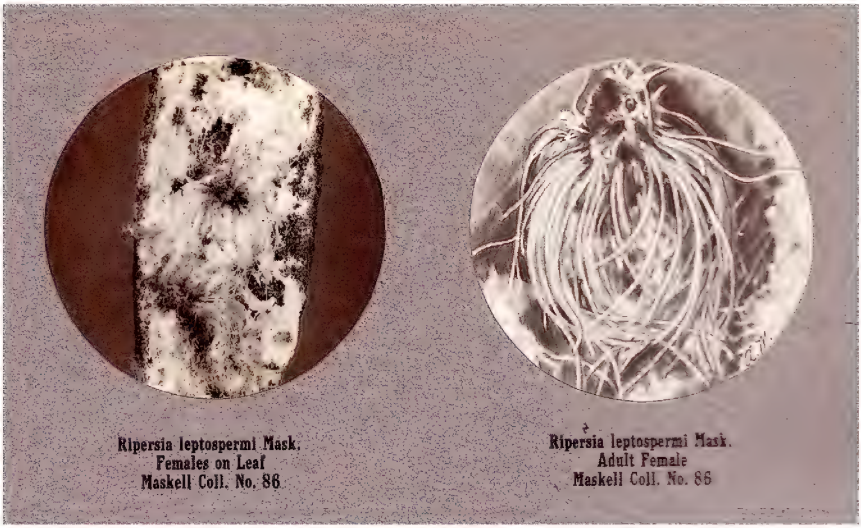

Fig. 1. Archival image of a drymount and a dry adult female of *Fimbriaticoccus leptospermi* (Maskell) showing the long wax filaments emanating from around the margin of the body. Photograph from the W.M. Maskell collection (No. 86), in the scale insect collection of the USNM, housed at the USDA Agricultural Research Service in Beltsville, MD, U.S.A.

(Fig. 1). Maskell (1889: p. 106) described the unmounted adult female as: ".. flattish, a little raised and carinated on the dorsum; outline sub-circular, or if in a depression of the leaf proportionately compressed; colour dark purple, covered with white meal; producing rich red colour when immersed in potash. From the edge of the body radiate all round a large number of very long, fine, white, cottony, curling filaments which are also slightly arched, forming a kind of bower, under which is a mass of more granular cotton, slightly tinged with yellow, in which the eggs are laid and hatched. The filaments are in tufts set close together, and their average length is about twice the diameter of the insect." Maskell also stated that the marginal tufts of long, white, cottony filaments were produced from "large projecting tubular spinnerets with wide bases", which clearly are the clusters of truncate spine-like setae found on each side of each body segment. Refer to the Diagnostic comments on the adult female for further discussion of wax secretion.

Slide-mounted adult female (Fig. 2) (measurements and counts combined for all 12 specimens if they overlap, otherwise in rounded parentheses () for 5 NZAC and USNM specimens from Sydney, and in square parentheses [] for the 7 specimens from Hartley). Body elongate ovoid (in young adults) to ovoid, (0.80–0.89) [1.26–1.50] mm long, (0.45–0.51) [1.00–1.17] mm wide; derm mostly membranous; segmentation distinct dorsally and ventrally on older specimens. Eyespots subcircular, with sclerotised centre 17–20 µm wide, surrounded by more lightly sclerotised region 23–37 µm wide. Antennae 190–240 µm long,

with 6 segments, with segment III longest; apical segment 28–40 µm long, 17–23 µm wide; segment III (92–105) [70–86] µm long, 23–30 µm wide at apex; 10 antennal trichoid setae, each 15–45 µm long, distributed as follows: 2 on I, 1 on II, 2 on III, 0 on IV, 2 on V and 3 on VI; 7 or 8 fleshy setae, each 12–25 µm long, confined to 3 apical segments, with 1 on IV, 1 on V and 3 thick and 2 or 3 thin setae on VI; 2 coeloconic sensilla on VI; a single campaniform sensillum on apical part of II. Labium apparently 3 segmented, 60–75 µm long, 60–65 µm wide across base (often rotated and not measured), with 2 pairs of setae on basal segment, 1 pair on segment II and 3 pairs on apical segment. Clypeolabral shield (tentorium) 100–120 µm long, 90–115 µm wide. Mesothoracic spiracles (28–35) [40–45] µm long; metathoracic spiracles (30–38) [40–50] mm long; peritreme width difficult to measure. Legs slender and, in young adults, very long relative to body size; hind legs with rimmed translucent pores dorsally and ventrally on anterolateral part of each coxa numbering (14–17 but hard to see) [17–30], absent on other segments but Sydney specimens with a few small light spots on all segments of all legs but especially near apex of femur; hind coxa 65–75 µm long, hind trochanter + femur 210–250 µm long, hind tibia + tarsus 305–365 µm long, claw 28–37 µm long, hind femur 43–50 µm wide; hind trochanter with longest seta 60–95 µm long; tarsal digitules of each pair of legs capitate and subequal, 48–55 µm long; claw digitules capitate and subequal, 25–37 µm long; claw denticle minute to apparently absent. Ratio of lengths of hind tibia + tarsus to trochanter + femur 1.44–1.52; ratio of lengths of hind tibia to tarsus 1.11–1.28. Anal ring (65–85) [90–110] µm long, (50–60) [70–75] µm in outside width, with 8 anal ring setae each (110–150) [160–195] µm long, and each half of anal ring with 12–16 pores on outer edge and 7–15 pores on inner edge. Anal lobes moderately developed, with light sclerotisation encompassing setae; an apical seta 190–240 µm long and 2 shorter hair-like setae, each 25–65 µm long, as well as 3 dorsal truncate spine-like setae, either subequal in length or of varying length per lobe, each 25–48 µm long, often with one seta (not necessarily longest one) more slender than other 2 setae.

Dorsum. Body margin with segmental setal clusters resembling mealybug cerarii, clusters numbering 12 pairs (including cluster on each anal lobe), each cluster with 3–24 truncate spine-like setae with number per cluster starting from head as follows: I (12–16) [14–21], II (16–19) [19–24], III (13–15) [11–22], IV (8–10) [9–13], V (9–10) [10–13], VI (8–11) [10–12], VII (9–10) [10–12], VIII (9–10) [10–12], IX (9–10) [10–12], X (8–9) [9–11], XI (7–8) [8–10], and XII (always 3 on each anal lobe); locular pores absent from within clusters but base of many truncate setae per cluster surrounded by 1–10 microtubular ducts; each microtubular duct 3–5 µm long and about 1 µm wide; in mature females each cluster of setae surrounded by very weak sclerotisation. Other setae thick, almost parallel-sided with rounded apex, 10–28 µm long, sparsely distributed across all segments, sometimes weakly associated with 1 or 2 microtubular ducts. Multilocular pores with a circular central area (but no central loculus) and 7 outer loculi, each pore (4.5–5.0) [5.0–6.0] µm in diameter, scattered sparsely

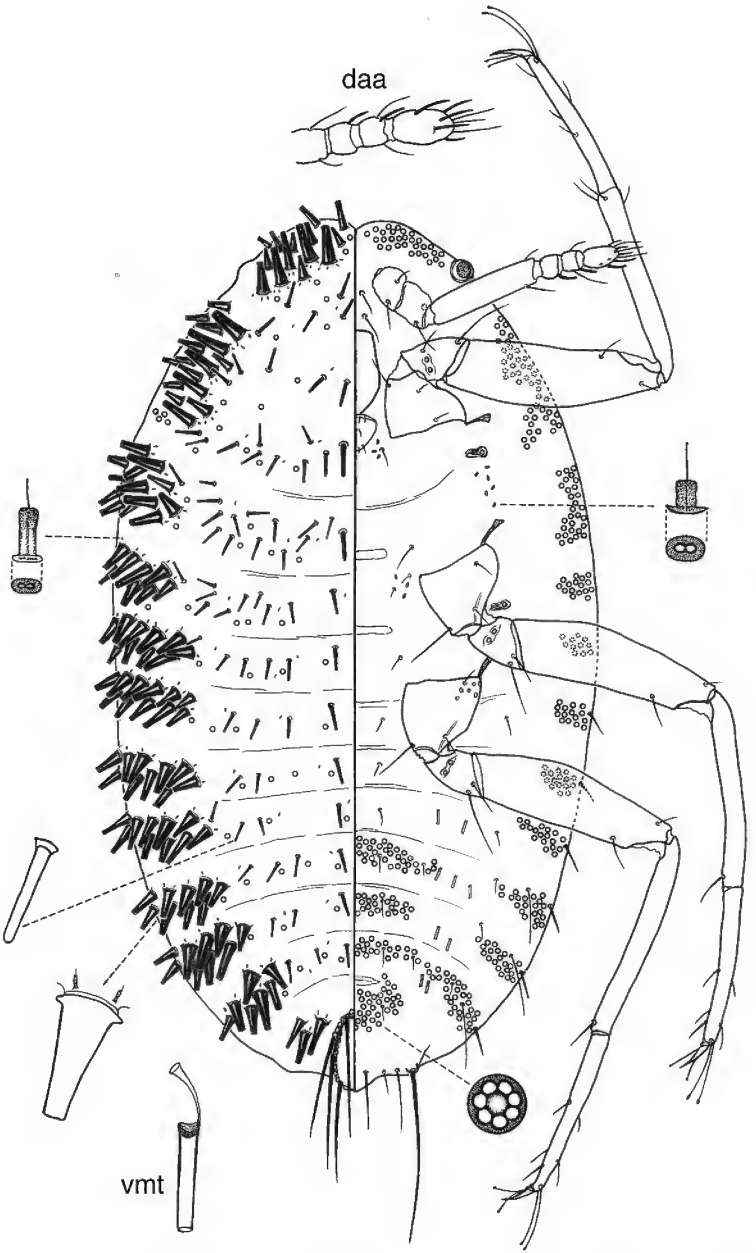

Fig. 2. Adult female of *Fimbriaticoccus leptospermi* (Maskell); daa, dorsal apex of antenna; vmd, ventral macrotubular duct.

across all segments. Macrotubular ducts absent. Microtubular ducts each 3–5 μm long, 1–2 μm in diameter and 2.0–2.5 μm across opening, which often appears bilocular, sparse, scattered among dorsal setae, but also at base of truncate setae (as described above).

Venter. Setae all hair-like, thin with flagellate apex, each 14–50 μm long, sparsely distributed across all segments. Suranal setae hair-like, usually slightly more robust than other ventral setae, each (60–80) [35–40] μm long. Multilocular pores each with circular central area (but no central loculus) and 7 outer loculi (a few rare pores with 5 or 9 loculi), each pore (4.5–5.0) [5.0–6.0] μm in diameter, distributed laterally in segmental clusters ventral to each marginal cluster of dorsal truncate setae, plus in a transverse band medially on each of abdominal segments V–VIII, but none medially to submedially on head and thorax. Macrotubular ducts each (23–25) [30–35] μm long, membranous towards opening and tending to concertina, 2.5–3.0 μm wide, with inner filament 13–18 μm long, and cup 4–5 μm across; sparsely distributed submarginally on each side of abdomen. Microtubular ducts resembling a bilocular pore from above, with long axis of rim about 3 μm across, each duct 3–4 μm long, with tube about 2 μm in diameter, present in a line or narrow band numbering 6–16 ducts posterior to each anterior spiracle and sometimes present singly or a few clustered medial to base of at least each mid leg.

Diagnostic comments. The adult female of *F. leptospermi* is highly distinctive due to the segmental marginal clusters of truncate spine-like setae. The only other eriococcid genus with which the adult female of *F. leptospermi* might be confused is *Sangicoccus* (originally described as *Haematococcus* Reyne, 1961, which was a preoccupied name), in which the adult females have marginal clusters of truncate, or sometimes bluntly pointed, spine-like setae, which secrete wax (Reyne 1961, 1965; Williams and Watson 1990; Kozár *et al.* 2009). Adult females of both genera also have macrotubular ducts confined to the ventral submargin of the abdomen [see Reyne (1961, figs 11 & 33)] and similar multilocular pores and microtubular ducts. However, *Sangicoccus* differs from *F. leptospermi* in the following features of the adult female (those of *F. leptospermi* in parentheses): antennae three segmented (six segmented); frontal lobes well developed (absent); legs poorly developed and short, with trochanter and femur usually fused (long, well developed and without fusion of trochanter and femur); coxa and femur of hind legs with irregularly shaped translucent pores on dorsal surface (on ventral and dorsal surfaces of hind coxa only); marginal clusters of spine-like setae on a sclerotised area (on unsclerotised or very weakly sclerotised area); dorsal setae of two kinds, larger ones with a striated surface and smaller ones with an unstriated surface (all of one kind, with surface unstriated, although medial setae largest); and ventral macrotubular ducts with a wide sclerotised area surrounding the orifice (without sclerotised area surrounding the orifice).

Many of the truncate setae of the adult females of *F. leptospermi* have a ring of microtubular ducts around their base, and the latter probably secrete wax that

encases the setae and forms the wax filaments described by Maskell (1889). Similar secretory setae occur in a few other eriococcids, such as many species of *Madarococcus* Hoy, 1962, which also have microtubular ducts at the base of some dorsal setae (Hardy *et al*. 2008). Reyne (1961) believed that the marginal wax filaments of *Sangicoccus obtusispinus* (Reyne, 1961) were formed by its conical marginal spine-like setae in conjunction with small tubular ducts at the base of the setae and that the dorsal wax tubercles were the product of the dorsal spines also in conjunction with small tubular ducts. The small tubular ducts referred to by Reyne (1961) are microtubular ducts based on their size (~4.0 x 1.5 µm) and morphology (minute tubes with a longitudinal partition, a small filament at the inner end and a double opening at the surface of the body).

The adult female of the eriococcid genus *Pedroniopsis* Green, 1926, known only from the type species *P. beesoni* Green, 1926, from India and Burma, also has truncate conical marginal setae although the setae each have a bifid apex and are arranged in a single marginal row, and there are no microtubular ducts at the setal base (Hodgson and Williams 2016). Furthermore, the female of *P. beesoni* has three-segmented antennae (six segments in *F. leptospermi*), quinquelocular pores only (cf. almost all pores with seven loculi), and an anal ring with six setae (cf. 8 setae).

Maskell's specimens from Sydney (non-type, collected in 1892) differ from the specimens collected at Hartley in several size-related features, although not in the sizes of the antennae or legs. The following are larger in the specimens from Hartley: body length and width (due to greater maturity of specimens); outer sclerotised part of each eyespot; length of third antennal segment; anal ring length and width; spiracle length (including apodeme); and length of longest of the three truncate setae on each anal lobe. In contrast, the suranal setae are longer on the Maskell specimens than on the females from Hartley. Although the counts of the number of truncate setae per marginal cluster overlap for females from Hartley and the Maskell specimens, usually the specimens collected at Hartley have one to several more setae per cluster. In addition, the microtubular ducts at the base of the larger truncate marginal setae are numerous (often 6–8 around base of each larger seta) on the females from Hartley than on the Maskell specimens (often only 2–4 visible per setal base). Maskell's adult specimens are weakly sclerotised because they are recently eclosed and thus microtubular ducts may be harder to see. All of the above differences may reflect genetic differences between the two populations or plastic phenotypic differences resulting from differing environmental conditions during development. Unfortunately, no specimens appear to remain from Maskell's type collection from South Australia, and the exact locality and month of collection of his subsequent collection from Sydney are unknown.

Description of first-instar nymph.

Unmounted specimens. Not seen by present authors. Maskell (1889: p. 107) described the crawler just after hatching as: ".. elongated, dark purple in colour,

slightly dusted with white meal; body segmented; anal tubercles conspicuous, with long setae".

Slide-mounted first-instar nymph (Fig. 3) (measurements and counts based on 9 nymphs, 1 from Maskell material and 8 from Hartley). Body 370–440 µm long, 185–250 µm wide; derm membranous; segmentation weak but distinct on abdomen. Eyespots each 12–17 µm wide, on body margin near base of each antenna. Antennae 83–90 µm long, with 5 or 6 segments, with segments III and IV usually fused to some degree (giving 5 apparent segments) and some segmentation distal to segment II obscured by partial fusion; apical segments (III–VI) together 56–65 µm long, 16–27 µm wide; antennal trichoid setae numbering up to 9, each 5–12 µm long, distributed as follows: 2 on I, 1 on II, 5 total on III–VI; 6 fleshy setae, each 8–12 µm long, confined to apical segments; 2 coeloconic sensilla near apex; a single campaniform sensillum on apical part of II. Labium conical, segmentation not apparent, 40–45 µm long, 40–48 µm wide across base. Clypeolabral shield 70–83 µm long. Spiracles each 16–20 µm long, without pores in or outside atrium. Legs well developed, subequal in size; hind coxa 20–25 µm long, hind trochanter + femur 65–80 µm long, hind tibia + tarsus 70–85 µm long with tibia shorter (27–35 µm) than tarsus (39–50 µm), claw 25–27 µm long, hind femur 21–30 µm wide; trochanter of each leg with one very long distal seta, 45–50 µm long (but difficult to see apex of seta on most specimens); paired tarsal digitules fine and slightly capitate, subequal, each 35–45 µm long; claw digitules very fine, difficult to see, subequal, 20–23 µm long; claw denticle absent. Ratio of lengths of hind tibia + tarsus to trochanter + femur 1.03–1.11; ratio of lengths of hind tibia to tarsus 0.63–0.85. Anal ring sclerotised, 38–40 µm long, 30–33 µm wide, with 3 pairs of anal ring setae each 60–75 µm long, and each half of anal ring with 7–9 pores on outer edge and 5 pores on inner edge. Anal lobes moderately developed, each with 3 dorsal setae: 2 robust (23–32 µm long) and 1 thin (10–22 µm long), 1 long hair-like ventral seta (35–50 µm long) and an apical seta up to 185 µm long.

Dorsum. Setae, including marginal setae, slender spine-like with rounded apex, each 8–23 µm long, longest on posterior abdominal margin, distributed in a transverse row of 6 setae per segment (except absent on VIII), segmentally arranged but lines more difficult to discern on thorax and head, with setae of adjacent body segments lining up to form 3 pairs of longitudinal rows: 1 submedial, 1 submarginal and 1 marginal. Pores and macrotubular ducts absent. Microtubular ducts, each 4–6 µm long, slightly longer on head and anterior thorax than on posterior thorax and on abdomen, opening bilocular (difficult to see), 1 medial to most marginal setae and lateral to most submedial setae.

Venter. Setae mostly hair-like, thin with flagellate apex, each 8–27 µm long, 1 submedial seta on each side of each thoracic segment and a few setae marginally on head and thorax, 6 setae across each abdominal segment with setae of adjacent body segments lining up to form 3 pairs of longitudinal rows: 1 submedial and 2 submarginal; apex of head with setae more robust, similar to those of dorsum.

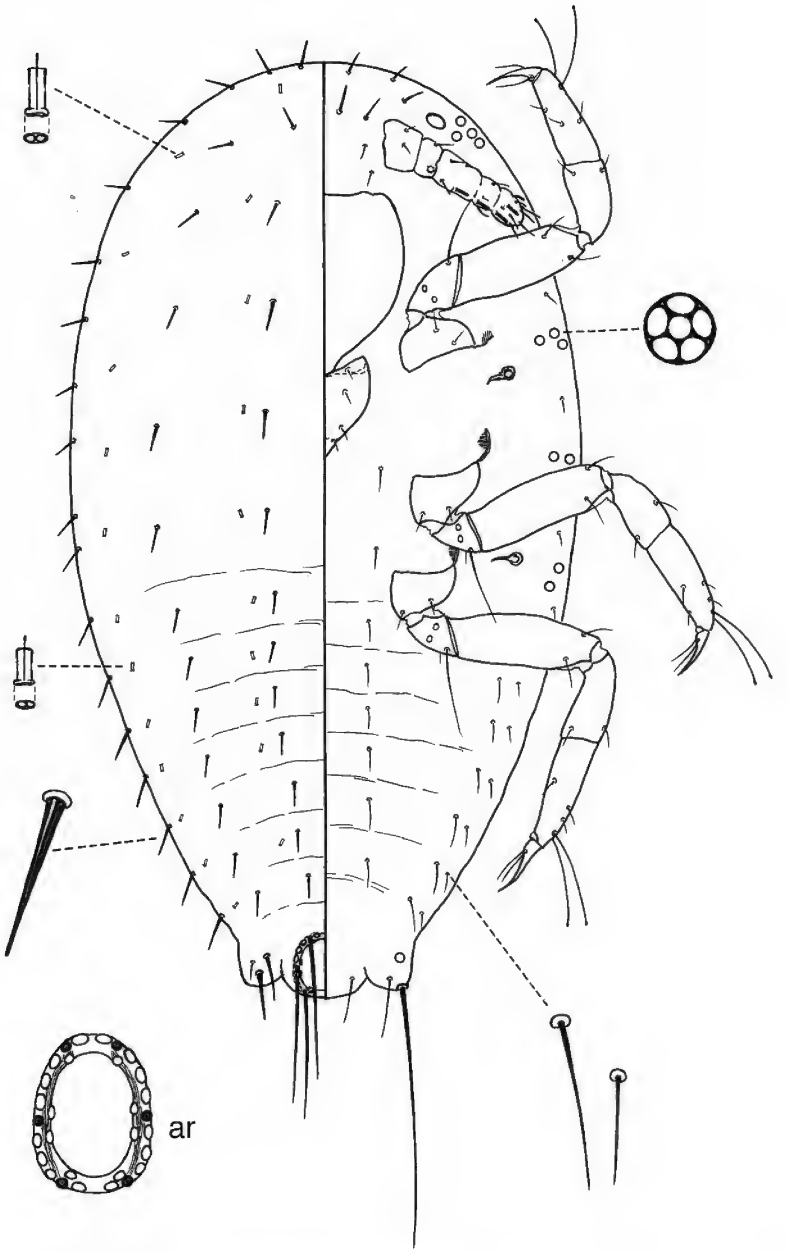

Fig. 3. First-instar nymph of *Fimbriaticoccus leptospermi* (Maskell). Inset of anal ring on lower left.

Suranal setae each 20–25 µm long. Multilocular pores each with a circular central loculus and 5 outer loculi, distributed singly or in segmental clusters marginally on each side of body as follows: 2–4 on head, 2–4 on thoracic segments I and II, 1or 2 on thoracic segment III and 1 on anal lobe. Macrotubular ducts and microtubular ducts absent.

Diagnostic comments. The first-instar nymph of *F. leptospermi* most closely resembles that of *S. obtusispinus*, which was described and illustrated by Reyne (1961). Five first-instar nymphs of *S. morrisoni* Kozár and Konczné Benedicty, 2009 (described in Kozár *et al.* (2009)), collected with the holotype, were listed but not described by Kozár *et al.* (2009) and those of the other two *Sangicoccus* species are not known. *Sangicoccus obtusispinus* differs from *F. leptospermi* in following features of the first-instar nymph (those of *F. leptospermi* in parentheses): apical segment of antenna apparently not showing evidence of segmentation and setae of apex include two very long trichoid setae (Reyne 1961, fig. 16) (apical segment showing evidence of segmentation and trichoid setae all short, up to 12 µm long, although apex of setae may have been broken); trochanter fused with femur of each leg (not fused); anal lobe with two long apical setae, 100 µm and 60–70 µm long, illustrated by Reyne (1961) as similar in thickness (two apical seta per lobe distinctly different in length and thickness); dorsal spine-like setae of two kinds: setae of mediodorsal double longitudinal rows robust and glandular, setae of marginal and submarginal rows thinner and latter two lines on each side of body close together (all setae similar in size and appearance and longitudinal lines more-or-less equally spaced); venter with four longitudinal rows of minute setae on abdomen (six longitudinal rows of setae on abdomen; these setae are difficult to see and it is possible that Reyne missed seeing one pair of rows); multilocular disc pores each with seven outer loculi and pores only in three marginal clusters (pores each with five outer loculi and in five clusters). The first-instar nymph of *Pedroniopsis* has not been described or illustrated and thus no comparison with *F. leptospermi* is possible.

Description of the second-instar female.

Unmounted specimen. Similar to a small adult female. Although Maskell (1893: p. 235) purportedly described this stage, he mistook very young adult females to be second-instar females (see Comments after the description).

Slide-mounted second-instar female (measurements and counts based on 1 nymph and 4 exuviae from the Maskell collection). Body elongate ovoid, 0.65–0.71 mm long, 0.38–0.40 mm wide; segmentation distinct dorsally and ventrally. Eyespots subcircular, each 15–18 µm wide. Antennae 110–140 µm long, with 6 segments, with segment III longest; apical segment 25–29 µm long, 15–18 µm wide; segment III 32–43 µm long, 20–22 µm wide; antennal trichoid setae, each 6–15 µm long, found on all segments; fleshy setae, each 8–15 µm long, confined to 3 apical segments, with 1 on IV, 1 on V and 3 thick and 2 or 3 thin setae on VI; 2 coeloconic sensilla on VI; a single campaniform sensillum on apical part of

II. Labium with segmentation indistinct, 40–50 µm long, 40–50 µm wide across base, 2 pairs of setae at base but other setae hard to see and count. Clypeolabral shield (tentorium) 85–95 µm long, 65–80 µm wide. Spiracles each 25–29 µm long, with peritreme 10–11 µm wide. Legs slender and long relative to body size; hind coxa 38–47 µm long, hind trochanter + femur 125–140 µm long, hind tibia + tarsus 65–85 µm long, claw 27–32 µm long, hind femur 28–33 µm wide; hind trochanter with longest seta about 60 µm long; tarsal digitules of each pair of legs capitate and subequal, 42–45 µm long; claw digitules capitate and subequal, 28–30 µm long; claw denticle minute to apparently absent. Ratio of lengths of hind tibia + tarsus to trochanter + femur 1.10–1.22; ratio of lengths of hind tibia to tarsus 0.74–0.90. Anal ring 40–50 µm long, 40–45 µm in outside width, with 6 anal ring setae, each 70–110 µm long, and each half of anal ring with 10 or 11 pores on outer edge and 3 or 4 pores on inner edge (difficult to see). Anal lobes moderately developed, with light sclerotisation encompassing setae; an apical seta 165–175 µm long and 2 shorter hair-like setae, one 17–20 µm and other 50–70 µm long, as well as 2 dorsal truncate spine-like setae, each 13–23 µm long but subequal in length on any specimen.

Dorsum. Body margin with segmental setal clusters resembling mealybug cerarii, clusters numbering 12 pairs (including cluster on each anal lobe), each cluster with truncate spine-like setae, each 12–26 µm long, situated on lightly sclerotized cuticle; first 3 pairs of clusters with most numerous truncate spine-like setae, with number per cluster starting from head as follows: I 5, II 5–7, III 4–6, and last 9 pairs of marginal clusters each with 2 truncate spine-like setae per cluster; locular pores absent from within marginal setal clusters but each cluster surrounded by up to 6 microtubular ducts at setal bases; each microtubular duct about 5 µm long and 1.5–2.0 µm wide. Other dorsal setae thick, almost parallel-sided with rounded apex, each 10–24 µm long, sparsely distributed across all segments, with larger setae weakly associated with 1 or 2 microtubular ducts. Multilocular pores with a circular central area and 7 outer loculi, each pore about 5.0 µm in diameter, scattered very sparsely across all segments. Macrotubular ducts absent. Microtubular ducts each up to 5 µm long and 2 µm in diameter, sparse, mostly associated with dorsal setae near midline and at base of marginal truncate setae (as described above).

Venter. Setae all hair-like, thin with flagellate apex, each 10–55 µm long, sparsely distributed (difficult to discern distribution). Suranal setae hair-like, each 40–50 µm long. Multilocular pores each with circular central area and 7 outer loculi, each pore about 5 µm in diameter, distributed laterally, ventral to each marginal cluster of dorsal truncate setae, in segmental clusters on each abdominal segment and in a narrow band on each of head and thorax. Macrotubular ducts and microtubular ducts absent.

In his description of the second-instar female, Maskell (1893) stated that the third segment of the antenna was as long as all of the rest of the segments together and that the tibia was longer than the tarsus. Neither of these conditions is true for the

second-instar female (see data above), but more accurately describes the adult female. Maskell also erroneously labelled one of his slides that has four young adult females as being the "2nd stage".

Comments on the male instars.

Maskell (1893) described the male pupa as being covered with white cotton but did not describe the actual insect. He described the adult male as being red with grey wings, having antennae each of 10 segments with the last four rather thick and short, and having a pair of dorsal and a pair of ventral eyes plus two ocelli.

The NZAC has one Maskell slide of an adult male and another slide of a second-instar male (not seen by the present authors), both collected in 1892 (see notes after Material examined above). In addition, two adult males of *R. leptospermi* were mounted by PJG from NZAC dry material of the same 1892 collection, which was sent by Mr Koebele from Sydney. These two adult males (in poor and very poor condition) have the following features:

Body: total length 800–900 µm, maximum width across thorax 280–320 µm; abdomen not attenuated, parallel-sided for most of length, tapering only at posterior segments; stout fleshy setae (fs) present on antennae and legs, absent on body. *Head*: pores absent; ocular sclerites without reticulations; ocelli present; preocular and postocular ridges well developed, dorsal mid-cranial ridge apparently present; antennae each 540–550 µm long, 10 segmented with segments III and IV longest; flagellar segments with both hair-like setae (hs) and fs, latter each 8–22 µm long, longest on segments IX and X, with 2–9 fs on each of segments III–X; at least 2 capitate setae present on each of segments V–X (perhaps more but setae are damaged). *Thorax*: quite well sclerotised, with relatively few hs present; wings each about 700 µm long, hamulohalteres absent; legs each with sparse fs on femur (1–5) and tibia (1–3), hs present on each segment but most numerous and strongest on tibia and tarsus, apparently only 2 campaniform sensilla, each oval in shape, in a transverse line on each face of each trochanter; tarsi each 2 segmented, with first tarsal segment very small. *Abdomen*: membranous except for segment XI (penial sheath, aedeagus and associated structures); glandular pouches present on abdominal segment VIII, each pouch with loculate pores and 2 setae (each about 100 µm long); penial sheath longer (130 µm) than basal width (95 µm), broad anteriorly, narrowing abruptly to a sharp apex.

Afifi (1968) and Hodgson (2020) gave accounts of the morphology of adult male eriococcids with descriptions and illustrations of a number of genera and species. The adult male of *F. leptospermi* is a typical eriococcid male and resembles males of species of *Acanthococcus* Signoret, 1875a, *Apiomorpha* Rübsaamen, 1894, *Calycicoccus* Brain, 1918, *Eriochiton* Maskell, 1887, and *Eriococcus* Targioni Tozzetti, 1868, in having a pair of glandular pouches on abdominal segment VIII, each with two long setae. It was not possible to place the adult males of *F. leptospermi* in one of the eriococcid groups mentioned by Hodgson (2020)

because there seems to be no completely reliable diagnostic morphology for each group based on adult males; there is wide variation in morphological structures among genera. The adult male of *F. leptospermi* seems to share a few features with some members of both the acanthococcine and Gondwanan eriococcid groups, however, only the rather specialist adult males of the Myrtaceae-feeding group (which are mostly gall living) have been described and illustrated for the Gondwanan group.

Discussion

Helen M. Brookes made two collections of similar looking scale insects at Hartley (a ghost town), South Australia, in 1960. One collection was the eriococcid *F. leptospermi*, which is the subject of this paper, and the other was the mealybug *Rastrococcus melaleucae*. Oddly both *F. leptospermi* and *R. melaleucae* have marginal segmental clusters of truncate spine-like setae. In *F. leptospermi* many of these setae have wax-secreting microtubular ducts surrounding their base, whereas the truncate setae of *R. melaleucae* are surrounded by trilocular pores that secrete white wax filaments. The convergent similarity of *Fimbriaticoccus* and *Rastrococcus* extends to their relatively long and slender legs and typically (but not in *R. melaleucae*) numerous multilocular pores, but these unrelated insects differ in the usual morphological features that distinguish mealybugs (i.e., presence of ostioles, a circulus and trilocular pores) from eriococcids (lacking ostioles, a circulus and trilocular pores).

The adult female of *Fimbriaticoccus* closely resembles the adult females of species of the eriococcid genus *Sangicoccus*, as noted above in the diagnostic comments. *Sangicoccus* is a tropical genus from Southeast Asia and Papua New Guinea and has four described species (Reyne 1961; Kozár *et al*. 2009). Although adult females of *Sangicoccus* have marginal clusters of truncate spine-like setae and some dorsal setae similar to *Fimbriaticoccus*, the genera differ in other respects (as discussed above in the Diagnostic comments). The first-instar nymphs of *F. leptospermi* and *Sangicoccus* are similar as far as can be determined from the description and illustration of the nymph of *S. obtusispinus* by Reyne (1961) (see Diagnostic comments above). However, the known host plants of *Sangicoccus* are all palms (family Arecaceae) (García Morales *et al*. 2019), whereas *Fimbriaticoccus* is known only from Myrtaceae. The morphological similarity of *F. leptospermi* and *Sangicoccus* species probably reflects a close relationship, but there are no molecular data available to provide another information source for determining relatedness.

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A NEW SUBSPECIES OF *ACRODIPSAS DECIMA* MILLER AND LANE, 2004 (LEPIDOPTERA: LYCAENIDAE: LYCAENINAE) FROM NORTHERN QUEENSLAND

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Abstract

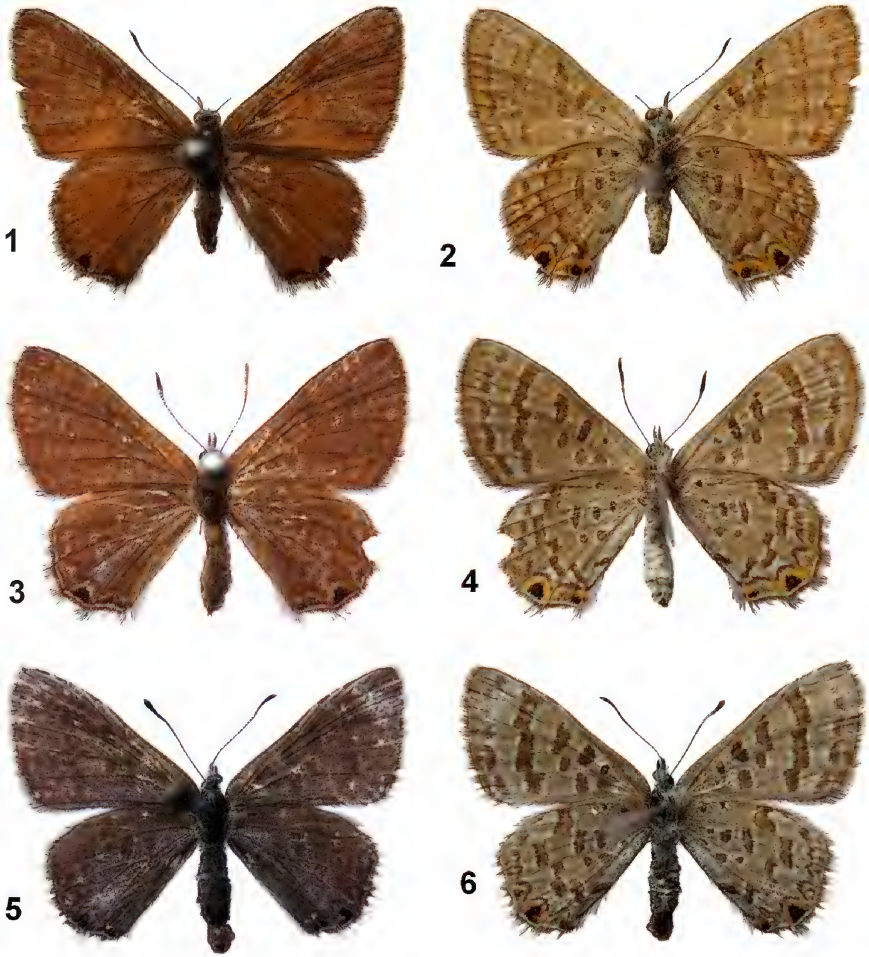
The first Queensland records of *Acrodipsas decima* Miller and Lane are recorded from between the Chillagoe and Almaden areas, west of Mareeba in northern Queensland. This population is located approximately 1500 km east of the single previously known location in the Northern Territory. Some noticeable adult differences, coupled with such a remarkably disjunct distribution justifies a new subspecies described here as *Acrodipsas decima mira* **subsp. n.** This new subspecies is compared with the nominotypical subspecies from the Northern Territory, in conjunction with discussion on its distribution, biology and behaviour.

Keywords: Ant Blues, species group, myrmecophagous, endemic, disjunct distribution

Introduction

The genus *Acrodipsas* Sands, 1980 (popularly referred to as Ant Blues) is endemic to Australia and currently contains eleven species, ten of which are well known for their habit of frequenting hilltops, usually during the middle part of the day through to early afternoon. Ant Blues are generally inconspicuous and are usually only encountered on specific hilltops, or occasionally closer to breeding sites where known. Life history details are known for only three species, the larvae of which are attended by single ant species and are myrmecophagous, feeding on the ant larvae and pupae within the ant nest (Braby 2000).

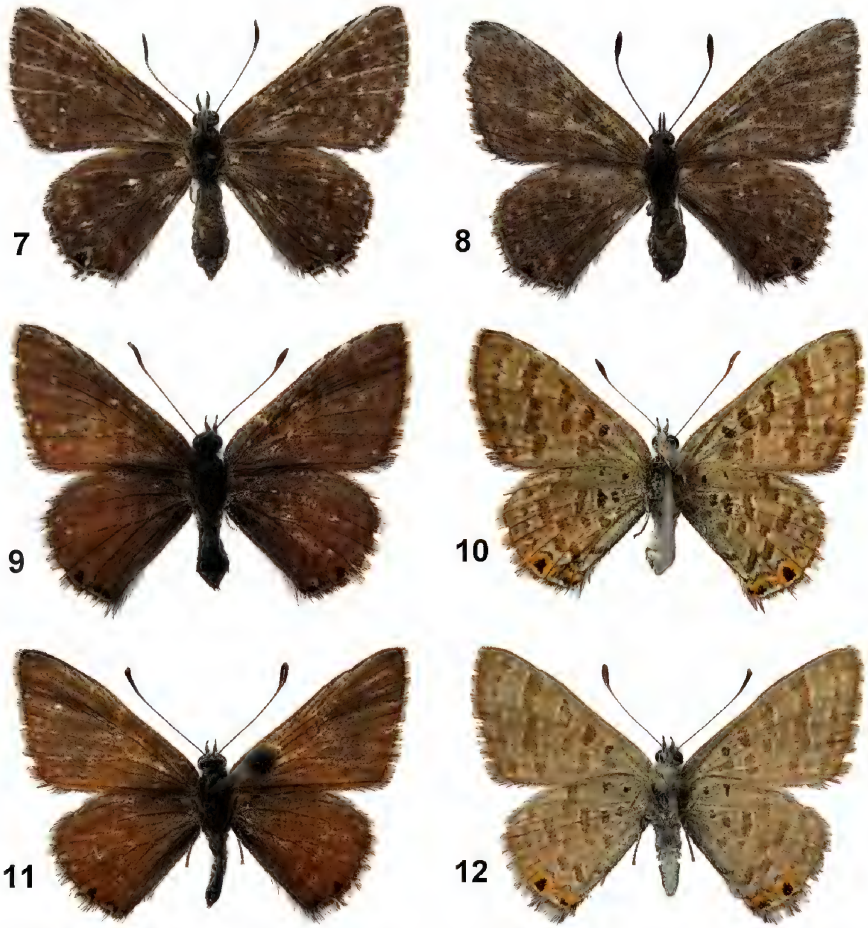
Male butterflies usually have their upper wings in shades of brown or grey, females usually in a darker brown or grey but with central blue areas in several species. Underside wing patterns are a light grey with a series of dark brown bands and spots. *Acrodipsas illidgei* (Waterhouse and Lyell, 1914) is the only species in the genus not recognised for hilltopping behaviour, as it usually inhabits coastal mangroves or their fringing vegetation, in south-eastern Queensland and north-eastern New South Wales (Braby 2000). Interestingly, two specimens of *A. illidgei* are known from inland localities in southern Queensland, a female from below the Toowoomba Range escarpment on a ridge at 750m asl (Lane 1991, Braby 2000), and a male from a swampy area near Leyburn (Sands and Sands 2003). The genus is divided into two species groups based primarily on the structure of the mid leg, where the fore and hind femora are swollen and the mid tibia is shorter than the first tarsal segment (being the *illidgei* group), or with the fore and hind femora not swollen and the mid tibia longer than the first tarsal segment (being the *myrmecophila* group) (Miller and Edwards 1978, Sands 1980). *Acrodipsas decima* Miller and Lane, 2004 belongs to the *illidgei* group (Miller and Lane, 2004), along with *A. hirtipes* Sands, 1980, *A. melania* Sands,



Figs 1–6. *Acrodipsas decima* subspecies, paratypes: (1–4) *Acrodipsas decima decima*: (1) male paratype dorsal, Mt Burrell, NT, 22 Mar. 1992, D.N. Wilson; (2) same male ventral; (3) female paratype dorsal, Mt Burrell, NT, 24 Apr. 1995, D.A. Lane; (4) same female ventral; (5–6) *Acrodipsas decima mira* subsp. n., paratypes: (5) female dorsal, 22 km SSE Chillagoe, Q, 12 Aug. 2020, D.A. Lane; (6) same female ventral.

1980, *A. arcana* (Miller and Edwards, 1978), and *A. mortoni* Sands, Miller and Kerr, 1997.

Acrodipsas decima was described from a small number of specimens (16 males, 3 females) all collected from a single hilltop in the Northern Territory, at Mt Burrell, Daly River Road, approximately 57 km west of Daly River township. Since the original specimens were taken during 1991–1995 very few additional



Figs 7–12. *Acrodipsas decima mira* subsp. n., paratypes: (7) female dorsal, Bismark Range, 6 km E Almaden, Q, 25 Oct. 2020, D.A. Lane; (8) female dorsal, Bismark Range, 6 km E Almaden, Q, 24 Oct. 2020, D.A. Lane; (9) male dorsal, 22 km SSE Chillagoe, Q, 14 Aug. 2020, D.A. Lane; (10) same male ventral; (11) male dorsal, 22 km SSE Chillagoe, Q, 12 Aug. 2020, D.A. Lane; (12) same male ventral.

specimens have been collected, and all were collected from the original hilltop (C.E. Meyer *pers. comm.*). The discovery of a population of *A. decima* in 2019 from the Chillagoe–Almaden district, approximately 100 km west of Mareeba in northern Queensland, was quite unexpected as this location is approximately 1500 km east of the only previously known locality at Mt Burrell.

The search for *Acrodipsas* species in the Chillagoe area arose from an historic observation made by Ian Hill (Fishery Falls, Queensland) and the late Bob Miller

during 2008, while staying in a cabin at the Chillagoe Caravan Park. Late one afternoon they saw a lycaenid butterfly resting on the front wall of the cabin, and collected it placing it in a plastic container. Suspecting that it was a species of *Acrodipsas*, they later photographed the resting butterfly with thoughts of confirming its identity. The next morning, while observing the butterfly it unfortunately escaped from the container and flew straight towards the door, walked under and through the small gap at door base, and disappeared not to be seen again. Several days later Ian and Bob showed the photograph of the specimen to one of us (DAL), and the initial assessment at that time, based on the underside wing markings, was that it was most likely a male of *Acrodipsas hirtipes* which had recently been recorded from a hilltop near the Palmer River on the Cooktown Road (Lane 1985). Recent searches from west of Chillagoe through to east of Almaden by one of us (DAL) have found populations of *Acrodipsas decima*, and these finds are the subject of this paper; the first Queensland record of the species and constituting a new subspecies.

Terminology follows that of Eliot and Kawazoé (1983), Braby (2000) and Kristensen (2003). The *phallus,* the organ of copulation, is also widely known as the *aedeagus*, a term considered inappropriate for use in the Lepidoptera (Kristensen 2003) as the aedeagus of other orders is believed not to be homologous.

Acrodipsas decima mira subsp. n.

(Figs 5–14)

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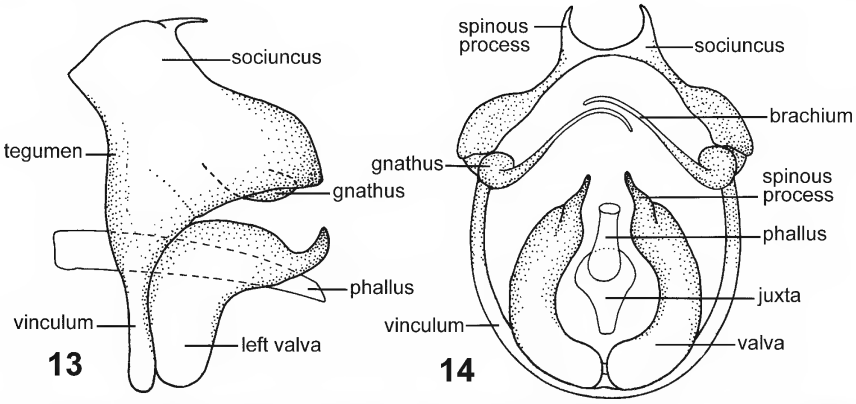
Types. Holotype ♂, limestone ridge, Chillagoe, Queensland, 17.1575°S, 144.5229°E, 18 Aug. 2021, D.A. Lane, a second label RN 31-076859 (Australian National Insect Collection, ANIC). *Paratypes,* QUEENSLAND: 1♂, same data as holotype, a second label RN 31-076860; 1♂ same data as holotype, a second label RN 31-076861 (all in ANIC); 1♂, same data as holotype, (in Queensland Museum, Brisbane); 3♂, limestone ridge, Chillagoe, 17.1575°S, 144.5229°E, 13 Sept. 2021, E. Petrie; 3♂, same data but 20 Sept. 2021; 2♂, same data but 21 Sept. 2021 (all in E. Petrie coll, Palm Cove, Cairns). 1♂, 1♀, limestone ridge, Chillagoe, 17.1575°S, 144.5229°E, 16 May 2021, D.A. Lane; 1♂, same data but 5 Aug. 2021; 5♂, same data but 18 Aug. 2021; 3♂, same data but 25 Aug. 2021; 1♂ Coonbeta Hill, 1 km E Chillagoe, 14 May 2021, D.A. Lane; 12♂, 18 km SSE Chillagoe, 28 Sept. 2021, D.A. Lane; 3♂, 22 km SSE Chillagoe, 16 May 2019, D.A. Lane; 6♂, same data but 6 Oct. 2019; 2♂, 1♀, same data but 4 Feb. 2020; 1♂, same data but 18 Mar. 2020; 3♂, same data but 27 May 2020; 2♂, same data but 29 May 2020; 3♂, same data but 1 Jun. 2020; 2♂, 2♀, same data but 12 Aug. 2020; 2♂, same data but 14 Aug. 2020; 6♂, same data but 22 Mar. 2021; 3♂, same data but 15 Apr. 2021; 1♂ 22 km SSE Chillagoe, 20 Oct. 2020, D.A. Lane and M Hopkinson; 1♂, 1♀, 22 km SSE Chillagoe, 6 Sept. 2021, D.A. Lane and C.E. Meyer; 1♂, same data but 7 Sept. 2021; 2♂, 1♀, same data but 10 Sept. 2021; 1♂, rocky knoll, 1.5 km SE Almaden, 7 Aug. 2020, D.A. Lane; 18♂, Bismarck Range, 6 km E Almaden, 13 Aug. 2020, D.A. Lane; 1♀, same data but 24 Oct. 2020; 1♂, 1♀, same data but 25 Oct. 2020; 1♂, same data but 15 Apr. 2021; 13♂, same data but 14 Sept. 2021 (all in D.A. Lane coll, Atherton). 10♂, 1♀, 22 km SSE Chillagoe, 6 Sept. 2021, C.E. Meyer and D.A. Lane; 2♂, same data but 7 Sept. 2021;



Figs 13, 14. *Acrodipsas decima mira* subsp. n., male, 22 km SSE Chillagoe, 4 Feb. 2020, D.A. Lane, genitalia dissection: (13) lateral view; (14) ventral view.

4♂, 2♀, same data but 10 Sept. 2021 (all in C.E. Meyer coll, Brisbane). 1♂ 22 km SSE Chillagoe, 15 Oct. 2020, M Hopkinson and D.A. Lane; 3♂, 1♀, same data but 20 Oct. 2020 (all in M Hopkinson coll, Kamerunga, Cairns).

Etymology. Named from the Latin *mira* which translates as surprise, not expected. *Mira* is the feminine gender of *mirum* (neuter) and *mirus* masculine (the genus *Acrodipsas* is feminine). It refers to the surprise discovery of this species in northern Queensland. The species name *decima* refers to the tenth known species at time of its publication in 2004.

Description of adult

Male (Figs 9–12). Head, palps, thorax and abdomen dark brown dorsally with lighter brown hairs; ventrally pale grey. Forewing length 9.5–11 mm, wingspan 20–23 mm; costa slightly bowed; apex sharply pointed; termen straight or weakly bowed in some specimens; dorsal apical two thirds brown; veins M_1 to 1A+2A with covering of black scales; basal third copper brown extending along inner margin but not to tornus, giving a two toned appearance, however a darker overall brown in some specimens. Hindwing termen convex; apex rounded, brown with a small semi-elliptical black spot (eye spot) between CuA_2 and 1A+2A; a pale blue terminal line between 1A+2A and CuA_2.

Ventral forewing light grey; a small subbasal band in cell; a broken submedian band and a partial median band between M_1 and M_3, and a broad prominent postmedian band not parallel to median band, all dark brown edged white; subterminal band dark brown with white edges parallel to termen.

Ventral hindwing light grey with a subbasal dark brown spot on $Sc+R_1$ and narrow band in cell; narrow median band between M_3 and CuA_2; prominent irregular postmedian band with sections displaced towards termen at M_2 and CuA_1, dark brown edged white; subterminal dark brown band crenulated, parallel to termen;

a prominent black spot within a bright orange semielliptical patch (eye spot) between CuA_1 and CuA_2; smaller black spot within a bright orange patch at tornus; terminal line light white.

Male genitalia (Figs 13, 14). Tegumen plus vinculum forming an elliptical cavity; sociuncus terminating in a pair of slightly inwardly curved spinous processes; brachia exceedingly long, almost spanning genital cavity so that their distal ends overlap; valvae large, broad, tending parallel-sided in ventral view constricting to a robust spine apically; juxta gradually taping basally from a pair of slender arms partly encircling phallus, the base terminating in a small squared apex inwardly curved; phallus tubular, narrowing a little distally, gently curved in lateral view most notable on distal third, the apex marginally sloping ventrally.

Female (Figs 5–8). Forewing length 10–12 mm, wingspan 21–25 mm; costa slightly bowed; apex pointed; termen straight, or weakly bowed in some specimens; dorsal forewing dark brown with scattered light blue scaling basally and along inner margin, extending to CuA_2; dorsal hindwing dark brown with prominent light blue tear-drop shaped area between 1A+2A and CuA_1, extending to M_3 in some specimens.

Ventral wing colour and markings similar to male with spotting and bands a little wider and heavier.

Diagnosis

Acrodipsas decima has been adequately described by Miller and Lane (2004), and all the Queensland specimens fit closely within that description. However, there are some differences noted: compared to the nominotypical *H. decima* from the Northern Territory (Figs 1–4), both males and females from Queensland (Figs 5–12) have a straighter forewing termen and a noticeably more pointed forewing apex (more strongly evident in males); the ventral forewing bands and spotting are more distinct and darker; the hindwing ventral tornal eyespot is a darker orange; and females have a more strongly defined blue "tear drop" mark on the dorsal hindwing (often extending to M_3), and scattered blue scaling on the dorsal forewing extending from inner margin to CuA_2 (more evident on fresh specimens).

The male genitalia taken from a specimen from 22 km SSE Chillagoe (Figs 13, 14) show no appreciable differences from a male from Northern Territory (cf. figure in Miller and Lane, 2004), also confirming the identity of the Queensland specimens as *A. decima*. Further, the legs of specimens from Chillagoe also have the fore and hind femora swollen and mid tibiae shorter than the first tarsal segment, as in *A. decima.*

Distribution and Habitat

Acrodipsas decima mira is currently known from the Chillagoe area to the Almaden area. There are records from Coonbeta Hill, 1 km E of Chillagoe, a limestone ridge at Chillagoe, a rocky knoll 18 km SSE of Chillagoe, a rocky

knoll 22 km SSE of Chillagoe, a rocky knoll 1.5 km SE of Almaden, and from the Bismarck Range approximately 6 km E of Almaden. These localities span a broad NW–SE area approximately 40 km in length. Undoubtedly the species extends beyond this area and may be far more widespread than is currently known, particularly to the west of Chillagoe where many suitable hilltops are yet to be investigated.

Typical of many *Acrodipsas* species, males frequent hilltops arriving around midday and females in the early afternoon. Hilltop types favoured by *Acrodipsas decima mira* range from granite outcrops to limestone ridges, and include Ironbark eucalypt areas on granite soils to vinescrub patches on limestone outcrops. Adults have been recorded from February to June, and from August to October. It may likely occur during most months of the year, seasonal conditions depending.

Interestingly, no other *Acrodipsas* species has yet been found in the Chillagoe area, although *Acrodipsas brisbanensis* (Miskin, 1884) occurs near Dimbulah (some 50 km east of the *A. decima mira* location), near Mount Garnet (Lane 1985), and near Walsh Bluff 10 km NW of Atherton. *Acrodipsas brisbanensis* is further distributed widely through eastern and southern Australia (Braby 2000). *Acrodipsas hirtipes* is known from the Palmer River area (Lane 1985, Braby 2000), some 130 km to the NNE of the *A. decima mira* location, as well as several sites on Cape York Peninsula (Braby 2000).

Acknowledgements

We thank Ian Hill and the late Bob Miller for drawing our attention to the historic observation of *Acrodipsas* species at Chillagoe. We also thank Mark Hopkinson (Kamerunga, Cairns) for his company and assistance in the field. Thanks are extended to Cliff Meyer and Grant Miller for providing photographs of Northern Territory specimens of *A. decima decima* in their collections. We are grateful to A.G. (Bert) Orr for his expert advice on the correct Latin interpretation of the subspecies name *mira*. Ed Petrie (Palm Cove via Cairns) also collected eight specimens from Chillagoe just prior to this manuscript going to press, and is thanked for providing his data records for inclusion. We thank two anonymous reviewers for their helpful comments.

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THE GENUS *AUSTROPHTHALMA* DAJOZ, 1966 (COLEOPTERA: LATRIDIIDAE: CORTICARIINAE) NEW TO AUSTRALIA, WITH DESCRIPTION OF A NEW SPECIES

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Abstract
The genus *Austrophthalma* Dajoz, based on a South African species, *A. raffrayi* Dajoz, is newly recorded from Australia and a new species, *A. monteithi* **sp. n.** is described from Queensland and New South Wales. The systematic relationships of the genus within the subfamily Corticariinae are also discussed.

Keywords: Latridiidae, Corticariinae, Australia, South Africa

Introduction
Austrophthalma Dajoz, 1966 is a monotypic genus containing the species *A. raffrayi* Dajoz, 1966 and based on three female specimens collected in the vicinity of the Cape of Good Hope, South Africa. The genus was distinguished from southern African species of *Melanophthalma* Motschulsky, 1866, *Corticaria* Marsham,1802 and *Corticarina* Reitter, 1880 by the absence of a visible scutellar shield, combined with the presence of a small, anteriorly-opening notch at the inner anterior angle of each elytron. The elytra were also described as having confused punctation, although the illustration shows at least partial seriation near the suture. The lateral edges of the pronotum and anterior portion of the elytra appear to be very slightly serrulate, and there are five abdominal ventrites with ventrite 1 much longer than the metaventrite. Several specimens were discovered in the ANIC and QMB collections which had the characteristics of the South African species, but differed in being larger, darker in colour with longer, slender antennae and stronger lateral pronotal teeth. Another feature not emphasised in Fig. 1 of Dajoz (1966), but possibly a distinguishing character of the genus, is the strong basal pronotal curvature (see below).

Materials and Methods
Morphological terms follow those used in Lawrence and Ślipiński (2021). Head length excludes the labrum and head width is that immediately behind eyes. Lengths of the mesoventrite and metaventrite exclude the posterior or anterior intercoxal processes, respectively. The description is based on complete dissections of paratypes from the same locality as the holotype. The following ratios are also based on a subset of the type series: 1) total length including head in mm; 2) length of body (pronotum plus elytra)/greatest width of combined elytra; 3) pronotal length at midline/greatest pronotal width; 4) elytral length at midline but including scutellar shield/greatest width of combined elytra; 5) elytral length/pronotal length; and 6) greatest depth, measured in lateral view from the highest point in the dorsal elytral curvature to the lowest point on the metaventrite/greatest width of combined elytra. Information on microstructure

and most measurements of antennomeres, mouthparts, male genitalia were made on specimens in glycerine using a Leitz Wetzlar compound microscope with 10× and 32× objectives. Habitus images (Figs 1, 2) were photographed at the Australian National Insect Collection in Canberra using a Visionary Digital Imaging System (Dun Inc.) a Canon camera with Visionary Digital lift and Canon MPE 65mm lens plus extender. Image stacking was accomplished with Zerene Stacker Pro. The Fig. 19 photomicrograph was made with a Dino-Eye AM4023XC Eyepiece Camera attached to a compound scope and DinoCapture 2.0 software. This image is a snapshot and did not involve image stacking. The remainder of the images from dissected specimens, however, were produced with Leica Digital camera mounted on a Leitz compound microscope and enhanced in Adobe Photoshop.

The following abbreviations have been used for institutions which have provided specimens for study, or which are repositories of types: ANIC: Australian National Insect Collection, CSIRO Australian National Research Collections, Canberra, ACT, Australia; FMNH: Field Museum of Natural History, Chicago, Illinois, USA; QMB: Queensland Museum, Brisbane, Qld, Australia.

Family Latridiidae
Subfamily Corticariinae
Genus *Austrophthalma* Dajoz, 1966

Austrophthalma Dajoz, 1966: 207.

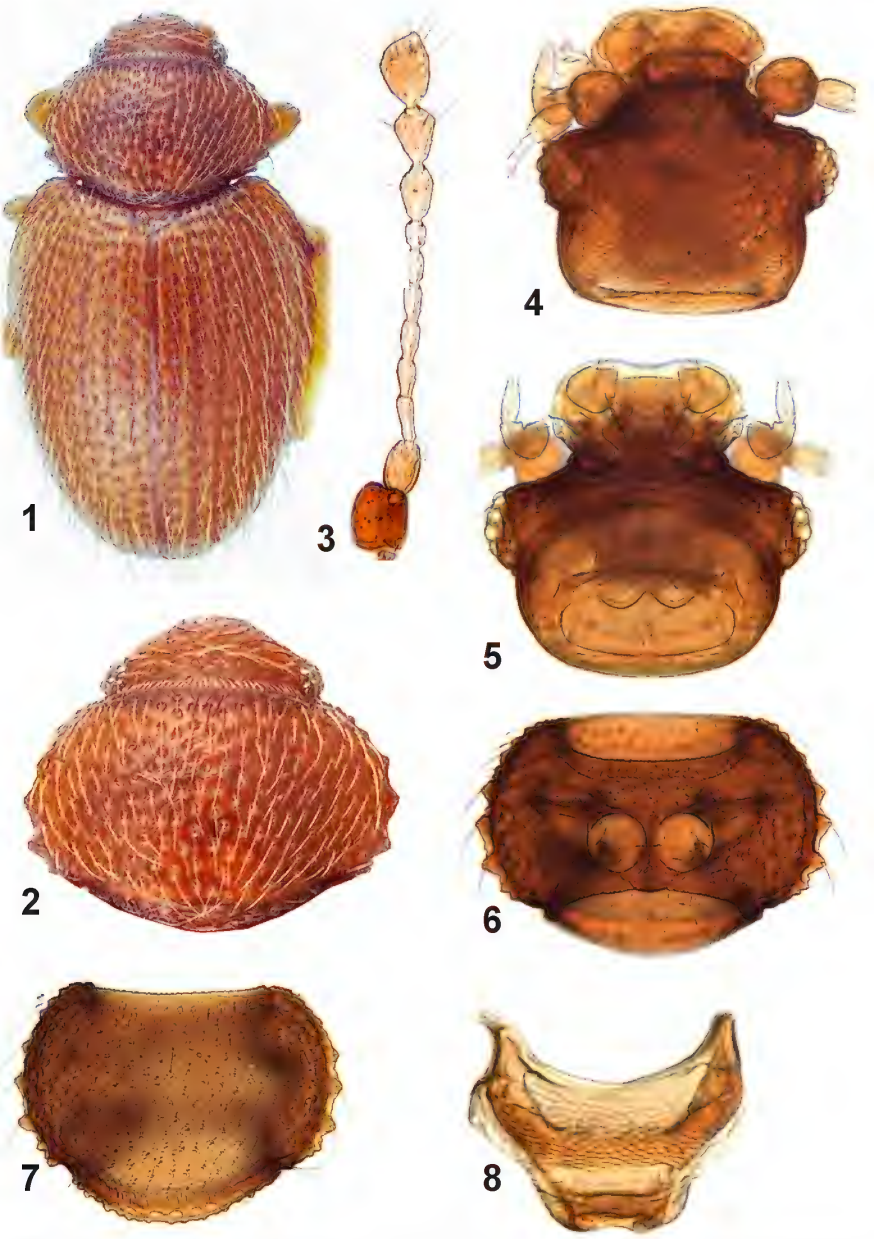
Type species: *Austrophthalma raffrayi* Dajoz, 1966, original designation

Diagnosis. This genus is placed in the subfamily Corticariinae based on the following characters: upper surfaces distinctly pubescent; clypeus on same plane as frons; frontoclypeal suture distinct, but not deep; procoxal cavities contiguous; head neither sulcate nor carinate; lateral edges of pronotal disc curved and serrate; elytra without costae or carinae, with punctures bearing long inclined hairs (Andrews 2002, Rücker 2018). Within the subfamily, it resembles *Caserus* Dajoz, 1969 (see Lawrence 2020), *Melanophthalma* and *Bicava* Belon, 1884 and differs from *Corticaria*, *Cortinicara* Johnson, 1975, and *Migneauxia* Jacquelin du Val, 1857, in having a distinct submentum, not fused to the base of the mentum. The short, broad body, metaventrite shorter than the first abdominal ventrite and loss of hind wings distinguishes the genus from all above-mentioned genera except *Caserus*, which differs from *Austrophthalma* in the much smaller size, very short, fine, dorsal vestiture, lack of teeth or serrations along the lateral edges of the pronotal disc, and the distinct notches at the posterior pronotal angles. A character not mentioned by Dajoz but characteristic of this group is the strongly curved posterior pronotal edge, which at its middle is well behind a line joining the elytral humeri (Fig. 1).

Austrophthalma monteithi sp. n.

Zoobank registration: urn:lsid:zoobank.org:act:948B41B4-94D9-4DA2-81DA-DC31E3F9E1B9

Holotype: male: '27.20S 152.46E [=27°20'S 152°46'E], Mt. Glorious QLD, 21 Dec. 1990, J. F. Lawrence / Berlesate ANIC 1136, leaf & log litter with fungi' (ANIC).

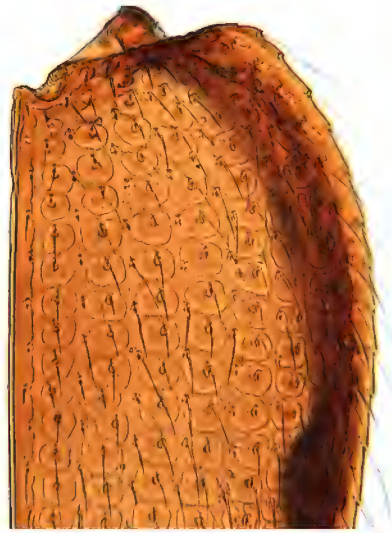


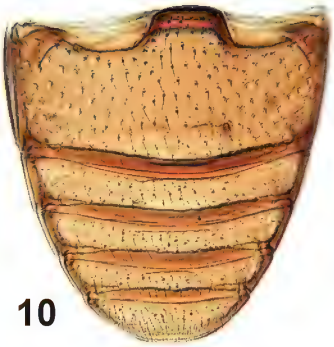
Figs 1–8. *Austrophthalma monteithi* sp. n., male. (1) habitus, dorsal; (2) head and prothorax, dorsal; (3) antenna; (4) head, dorsal; (5) head, ventral; (6) prothorax, ventral; (7) prothorax, dorsal; (8) scutellum.

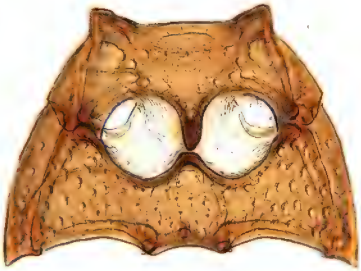
Paratypes: Australia: Queensland: Binna Burra (28°12'S 153°32'E), 800 m, rainforest, 12.iii.1997, QM Berlesate 919, sieved leaf litter, Monteith & Russell (1, QMB); Conondale Range, Lobster Creek, 20.viii.1995, ex litter, J. Kirkwood, D. Walter (1, QMB); Lamington NP near O'Reilly's (28°14'S 153°08'E), 25.x.1993, ANIC Winkler 1687, leaf & log litter, S.A. Ślipiński, J.F. Lawrence (5, ANIC); Lobster Creek, Conondale Range, 20.viii.1995, ex litter, J. Kirkwood, D. Walter (1, QMB); Mt Glorious (27°20'S 152°48'E), 21.xii.1990, ANIC Berlesate 1136, leaf & log litter with fungi, J.F. Lawrence (5, ANIC); Mt Glorious, 750 m, 16.v.1997, QM Berl. 945, G. Monteith (4, QMB, ANIC); Mt Tenison Woods (27°19'S 152°44'E), 750 m, rainforest, 15.v.1997, QM Berlesate 935, sieved litter, G.B. Monteith (3, QMB, ANIC); Polly Creek, Garradunga (17.455°S 146.02°E), 66 m, 3–30.xii.2009, Malaise 3, 19580, J. Hasenpusch (1, QMB). New South Wales: Mt Warning NP (28°42'S 153°18'E), 400 m, 19.vi.1993, ANIC Berl. 1656, subtropical closed forest, litter in stream bed, D.S. Chandler (1, ANIC); Nightcap NP, Mt Nardi (28°33'S 153°17'E), 700 m, 4.i.1987, FMHD #87-178, Berl. leaf & log litter, A. Newton, M. Thayer (2, FMNH, ANIC).

Diagnosis. This species may be distinguished from the South African *Austrophthalma raffrayi* Dajoz, 1966 in the following ways (based on the original text and figures in Dajoz 1966): size larger, antennomeres 3–6 all distinctly longer than wide; lateral pronotal teeth much larger; dorsal vestiture dual, seriate and consisting of longer setae; hind edge of the pronotum more strongly curved.

Description. Length 1.10–1.40 mm (1.23 ± 0.07) mm (n= 19). Body (Fig. 1) 1.54–1.76 (1.62) times as long as wide; greatest depth 0.58–0.71 (0.65) times as great as elytral width. Colour yellowish-brown to dark reddish-brown, with head and prothorax darker than elytra, undersides yellowish-brown, legs yellow to brown, antennae and mouthparts yellow. Head (Figs 4, 5) 0.74 times as long as wide; eye 0.17 times as long as head width, vertically oval, coarsely facetted; surface of frons and vertex coarsely and irregularly punctate; temples 0.33 times as long as eyes and sharp; neck absent. Antennae (Fig. 3) at least 1.7 times as long as head width, scape subglobular and darkly pigmented; remaining antennomeres lightly pigmented; pedicel slightly elongate and all remaining antennomeres distinctly longer than wide; club slightly shorter than antennomeres 3–8 combined and 6 times as long as wide. Subantennal grooves and genal ridges absent. Pronotum 0.61–0.71 (0.66) times as long as wide, widest at middle; anterior edge truncate; anterior angles not produced forward; sides (Figs 2, 6, 7) each with 4 or 5 larger teeth; posterior angles obtuse; posterior edge (Fig. 7) strongly rounded, lined with a number of minute teeth; disc moderately convex, surface coarsely and densely punctate, the punctures at least twice as wide as an eye facet and separated by less than half a puncture diameter; interspaces finely sculptured producing shiny surface. Prosternum in front of coxae (Fig. 6) about equal to length of coxal cavity; prosternal process flat, at middle 0.17 times as wide as mid length of coxal cavity, expanded posteriorly with broadly rounded apex; postcoxal processes 0.33 times as thick as length of coxal cavity and meeting prosternal process; cavities closed externally and internally. Procoxae subconical, slightly projecting with long internal extensions; trochantins concealed. Scutellar shield not visible externally; concealed scutellum (Fig. 8) 0.6 times as long as







Figs 9–14. *Austrophthalma monteithi* sp. n., male. (9) anterior portion of elytra, showing anteromesal notch, oblique anterior edge and position of mid-lateral interlocking cavity; (10) abdomen; (11) pterothorax with coxae removed; (12) mesotibia and tarsus; (13) mid-lateral portion of elytra showing position of interlocking cavity; (14) section of elytra showing punctation and vestiture.

wide and 0.67 times as wide as anterior edge of one elytron, with shield strongly transverse and weakly concave at apex. Elytra (Fig. 1) 1.09–1.26 (1.16) times as long as combined width and 2.27–2.84 (2.51) times as long as pronotum, widest at middle; anterior edge (Fig. 9) strongly oblique so that a line joining the outer anterior elytral angles is anterior to the posterior extent of the pronotum; mesal end of anterior edge with small, anteriorly opening notch; sides strongly curved without distinct margin and apices conjointly rounded; disc more or less evenly convex, without distinct humeri, with internal cavity (Figs 9, 13) at about middle into which metepimeral lobe fits to form an interlocking device; each elytron

(Figs 1, 9, 13, 14) with 8 rows of larger subquadrate punctures, alternating with rows of smaller punctures, from which longer and shorter, inclined to suberect, setae arise. Epipleura oblique and partly visible laterally, moderately broad anteriorly but strongly narrowed behind middle. Mesoventrite (Fig. 11) 0.55 times as long as wide, widest posteriorly with truncate anterior edge widely separating mesepisterna; intercoxal process narrowly rounded; mesocoxal cavities separated by 0.25 times diameter of a cavity, laterally closed. Metaventrite (Fig. 11) 0.33 times as long as wide, widest posteriorly; anterior edge truncate; surface finely punctate; discrimen absent. Metanepisternum about 5 times as long as wide; metepimeron with hyaline lobe, which fits into lateral elytral cavity. Metacoxae separated by 1.5 times shortest diameter of one coxa. Metendosternite with short broad stalk and long narrow lateral arms. Hind wings absent in both sexes. Abdomen (Fig. 10) about 0.9 times as long as wide; first ventrite 2.5 times as long as second, without postcoxal lines and with truncate intercoxal process; ventrites 2, 3, 4 and 5 = 0.4, 0.35, 0.30 and 0.50 times as long as ventrite 1, respectively; fifth ventrite 0.4 times as long as wide and broadly rounded at apex; a lightly sclerotised sixth ventrite (sternite VIII) exposed in some males. Spiculum gastrale (sternite IX, Fig. 15) 3.5 times as long as aedeagus; penis (Figs 15–17) 1.7 times as long as wide, widest at base with sides subparallel to posterior third, then converging to subacute apex; flange 0.84 times as long as penis, widest at base, with sides strongly converging beyond middle to acute apex; tegminal strut and endophallus (Figs 15, 18) 2.4 times as long as penis. Females very similar to males externally, and sexes are difficult to separate; some males may have an additional abdominal ventrite exposed and in others the penile apex may be exposed. Ovipositor (Fig. 19) relatively simple, without distinct lobes, but with paired, subparallel struts; internal tract containing a spherical capsule.

Distribution. Most specimens are from south-eastern Queensland and north-eastern New South Wales, with one from the Queensland Wet Tropics

Biology. Most specimens were extracted from sifted leaf or leaf and log litter with Berlese funnels, with one from a malaise trap.

Acknowledgments

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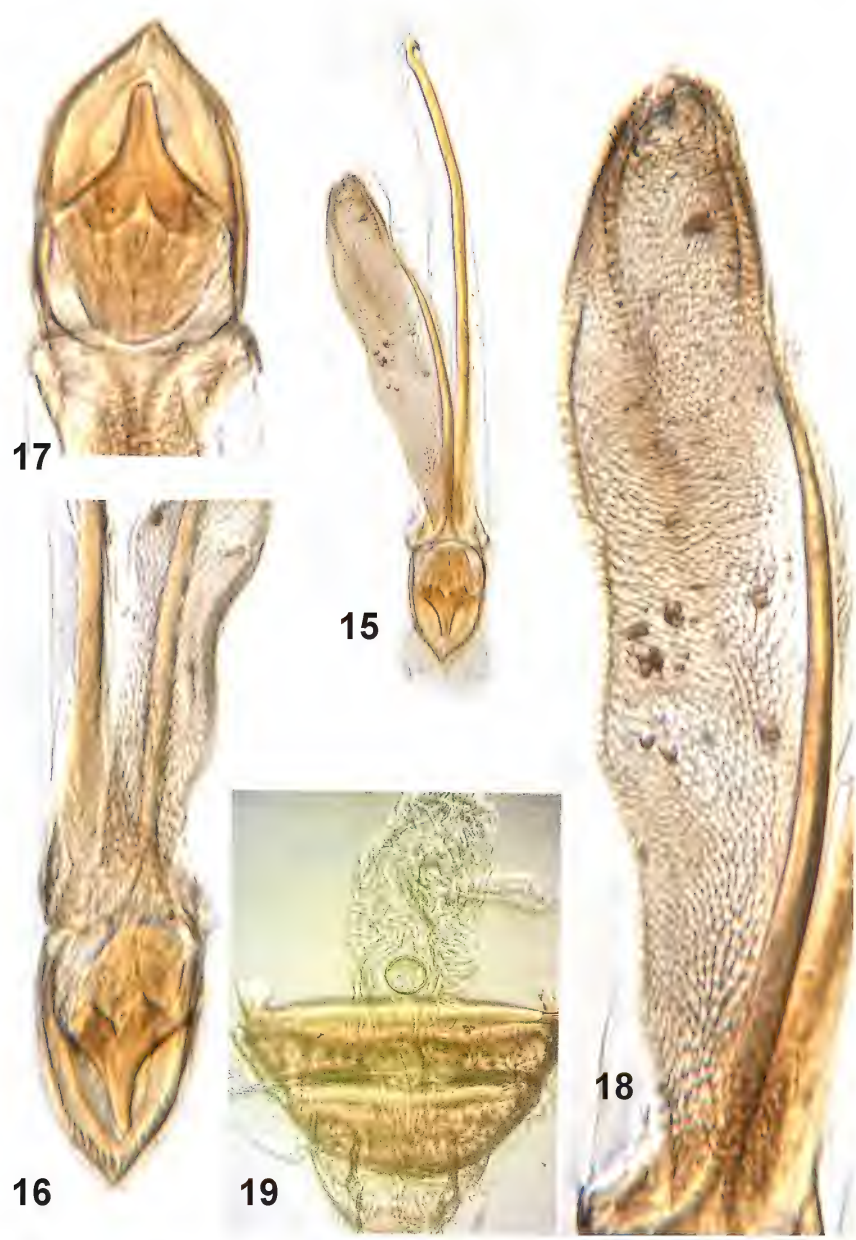

Figs 15–19. *Austrophthalma monteithi* sp. n. (15–18) male; (15) aedeagus and spiculum gastrale, dorsal; (16) apical half of aedeagus; (17) penis and flange, dorsal; (18) endophallus and tegminal strut; (19) female abdominal apex and ovipositor.

staff of the Queensland Museum, Brisbane, including Geoff Monteith, Susan Wright and Karin Koch for providing important study material during this difficult period. We also acknowledge the assistance provided by the two referees and the editorial staff.

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NATURAL HISTORY OF THE AUSTRALIAN TORTOISE BEETLE, *NOTOSACANTHA DORSALIS* (WATERHOUSE, 1877) (COLEOPTERA: CHRYSOMELIDAE: CASSIDINAE: NOTOSACANTHINI) WITH SUMMARY OF THE GENUS IN AUSTRALIA

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Abstract

The old-world tribe Notosacanthini is hypothesized as a transitional group between "hispine" leaf miners and exophagous tortoise beetles in the Cassidinae tree of life. Their biology, morphology, and genetics may help clarify evolution in the subfamily, yet few species have been studied deeply. Detailed field and rearing studies were conducted for *Notosacantha dorsalis* (Waterhouse) on the phyllodinous shrub, *Acacia crassa* Pedley (Fabaceae), in Queensland, Australia. Adults feed on phyllode tissue by biting linear, parallel grooves in the leaf-like phyllode surface. Solitary eggs are laid in short, shallow grooves bitten into the phyllode surface and coated with secretion then with faeces. Hatching larvae mine within the phyllode, depositing frass and larval exuviae near the hatched egg capsule. After consuming most resources of the initial phyllode, larvae cut their way out of the original mine (termed the primary mine) and re-enter a second phyllode, via an entry cut in the cuticle, to make a secondary mine. This entry cut serves to eject frass and exuviae. After a period of feeding, the secondary mine serves as the pupation chamber and the adult exits via the entry cut. We outline two processes for determining the number of instars for mining larvae which showed that *N. dorsalis* has four instars. Two hymenopteran parasites were collected. Museum specimens of Australian *Notosacantha* were examined to assess species and their distributions.

Key Words: *Acacia*, leaf-miner, Australia, endemic, life history, parasites, distribution

Introduction

Notosacanthini is a morphologically distinct tribe that is hypothesized as a transitional group between "hispine" leaf miners and exophagous tortoise beetles in the Cassidinae tree of life (Gressitt 1952; Gressitt and Kimoto 1963; Zaitsev and Medvedev 1982; Medvedev and Eroshkina 1988; Borowiec 1995; Staines 2002; Chaboo 2007). Inadequate knowledge of ecology, life cycles, and morphology of species of the following tribes—Aproidini, Basiprionotini, Cryptonychini, Delocraniini, Epistictini, Eurispini, Hemisphaerotini, Imatidiini, Leptispini, and Notosacanthini—leave many unanswered questions about their relations to each other and what could be evolutionary steps between the very different lifestyles, particularly of larvae, with leaf-mining and exposed leaf chewing and their correlated morphologies (Crowson 1955).

Notosacanthini comprises three extant genera, *Herminella* Spaeth, 1913 (4 spp.), the monotypic *Hermosacantha* Borowiec and Świętojańska, 2014a, and *Notosacantha* Chevrolat, 1837 as well as the extinct *Eosacantha* Chaboo and Engel, 2009. *Notosacantha* currently comprises 271 recognized species that

range from southern Africa and Madagascar to India and China, and through S.E. Asia, Philippines and Indonesia to New Guinea and Australia (Borowiec and Świętojańska 2012–2019). The adults have the pronotum and elytra explanate and with large punctures, the pronotal margin deeply indented exposing the head dorsally (as in the related tribe Hemisphaerotini), and the elytra with irregular raised costae and tubercles (Maulik 1919; Medvedev and Eroshkina 1988; Borowiec *et al.* 2013). Other diagnostic features are the vertex expanded anteriad into plates that overlap the antennal bases (Gressitt 1952; Medvedev and Eroshkina 1988), the antenna short with an apical club comprised of antennomeres with single longitudinal grooves and striations (Chaboo 2007: 99, Fig. F), and the aedeagus with a pair of lateral lobes (Chaboo 2007: 143, Figs D–E). Borowiec and Takizawa (1991) suggested some species-groups based on patterns of costae and tubercles; they also pointed out a sexual dimorphism with females having 10 antennomeres and males 11.

Host plants have been documented for 14 species of *Notosacantha* (Borowiec and Świętojańska 2012–2019; Table 1). All known hosts are eudicotyledons. *Notosacantha* is unusual in having leaf-mining larvae in the very few species for which life history information is available. Both Chaboo (2007) and Świętojańska (2009) summarize the literature on cassidine immature stages, including four species of *Notosacantha.* Illustrated descriptions of juvenile stages are available for just two species: *Notosacantha vicaria* (Spaeth, 1913) based on larvae and pupa on *Carallia brachiata* (Lour.) Merr. (Rhizophoraceae) in India (Rane *et al.* 2000) and *Notosacantha siamensis* (Spaeth, 1933) based on larvae and pupae on *Phyllanthus emblica* L. (Euphorbiaceae) from Vietnam (Medvedev and Eroshkina 1988). Others report brief notes with line drawings: pupa of *N. sauteri* (Spaeth, 1914) (Kimoto and Takizawa 1997; Lee and Cheng 2007), larva of *N. siamensis* (Kimoto and Takizawa 1997), egg, larva and pupa of *Notosacantha castanea* (Spaeth, 1913), and photo of a larva of *Notosacantha ihai* Chûjô, 1958 (Borowiec and Świętojańska 2014b:207). These studies reveal that larvae of *Notosacantha* do not retain an exuvio-faecal shield, as is usual in tortoise beetles. The keys to larvae in Kimoto and Takizawa (1997) for *Notosacantha* are contradictory: p537, couplet 3(2) indicates "larvae bearing exuviae and excretions on caudal processes" but p546 has "leaf-miner lacking body processes." Heron (2018) gives photographs of larval and pupal mines in South Africa for *Notosacantha badia* (Boheman, 1850) on leaves of *Gymnosporia nemorosa* (Eckl. & Zeyh.) Szyszyl. (Celastraceae) and of *Notosacantha laticollis* (Boheman, 1862) on *Canthium inerme* (L.f.) Kuntze (Rubiaceae). Monteith (1991a) briefly records and figures adult feeding, the egg capsule and larval leaf mining for the Australian *N. dorsalis* (Waterhouse, 1877) on *Acacia crassa* Pedley, 1974 (Fabaceae). The food plant was known from 1979–80 collections made by G.B. Monteith and the late M. DeBaar at Braemar State Forest and deposited in Brisbane museum collections. A colour photograph of *N. dorsalis* and adult feeding grooves on *A. crassa* at Barakula

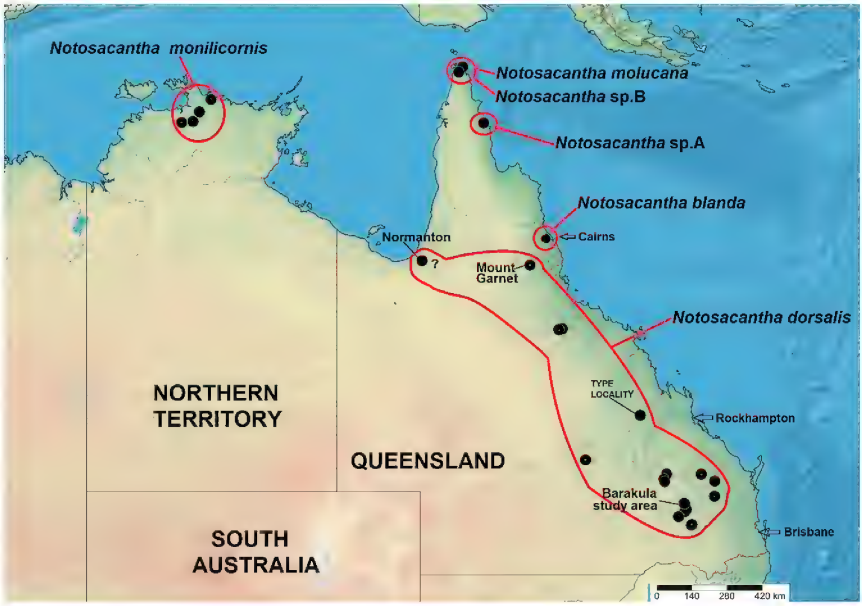


Fig. 1. Map of north-eastern Australia showing distribution of *Notosacantha* specimens in Australian museum collections. See text for explanation of species names used on the map.

State Forest, with speculative text, is given by Hawkeswood (1987, 1989) with corrections noted by Monteith (1991a) but repeated unchanged (Hawkeswood 1994, 2003; Jolivet and Hawkeswood 2005).

Four nominal species of *Notosacantha* are recorded in the literature from Australia (Borowiec and Świętojańska 2012–2019). Three of these were described from Australia, viz. *N. dorsalis* (Waterhouse, 1877), *N. monilicornis* Spaeth, 1913 and *N. blanda* (Spaeth, 1932). The fourth, *N. molucana* (Boheman, 1850), was described from Ambon in the Maluku Archipelago of Indonesia and subsequently recorded from New Guinea and from 'Cap. York' in Australia by Spaeth (1913). A preliminary review of the status of literature and museum records of the genus from Australia is given in the present paper.

This paper is the first step in a systematic study of Australian species of *Notasacantha*. It reports on the natural history and distribution of *N. dorsalis* based on field work, rearing of the life cycle, and on study of museum specimens by authors GM and VS over 2018–2021. Morphology of the immature stages will be presented in a subsequent paper.

Materials and Methods

This study was conducted under permit WIF418701617 issued by Queensland Department of Environment and Science to the Entomological Society of

Queensland (Principal Investigator: Christine Lambkin). Data and specimens were collected during ~18 months of field work, life cycle rearing, and study of museum specimens. Author initials are used below for specific research efforts.

Field study. Live populations of *N. dorsalis* were first discovered on the host plant, *Acacia crassa* (Fabaceae) by GM at two localities in 1979–80 in Braemar State Forest, Queensland. Some initial observations were made on their leaf mining and parasites then by GM and the late Murdoch De Baar of the Queensland Department of Forestry.

For the present comprehensive study, live populations were studied by GM and VS at AUSTRALIA: Queensland, Barakula State Forest (referred to as Barakula hereafter) on *Acacia crassa* (Figs 2–4). The locality is 300 km NW of Brisbane. Barakula comprises 283,000 ha of relatively undisturbed open forests and woodlands dominated by tree species of *Eucalyptus, Angophora*, *Corymbia* (Myrtaceae), *Allocasuarina* (Casuarinaceae) and *Callitris* (Cupressacae) and with an understory of scattered shrubs which include many species of *Acacia*. The beetle occurs patchily on the host plant within Barakula. Most observations were made along Big Break Road, near the Forest Station, at -26.434°S X 150.507°E (elev. 340m), where beetles consistently occurred. At this site the vegetation type is classified as Regional Ecosystem 11.5.1 under the system developed for Queensland (Sattler and Williams, 1999) which is woodland on Caenozoic sand plains. Rainfall is around 550 mm per year with most rain in summer. The area is within the Brigalow Belt Biogeographic Region of Australia (Thackway and Cresswell, 1995).

The field site was visited six times during 2018–2021: 1–3 Oct. 2018, 19–20 Oct. 2018, 17–18 Dec. 2018, 27–28 Feb. 2019, 5–6 June 2019, and 4–5 Sept. 2021. Observations were made in the field and many specimens of all stages were taken to Brisbane for rearing and life cycle study.

Temperature range of study sites. As a rough guide to temperature range at the Barakula field study site and the Brisbane rearing site, the following summer and winter average maxima and minima are taken from the Bureau of Meteorology (2021) website: Brisbane: summer 20.4–29.2°C, winter 10.2–21.4°C; Barakula: summer 19.1–32.9°C, winter 4.5–20.2°C.

Life cycle study. Five young plants of *A. crassa* were transplanted from Barakula, potted, and grown in the Brisbane garden of author GM during October 2018 to February 2020. Plants were enclosed with large, suspended netting sleeves (Fig. 6) which could be easily lifted off for observations. Adult beetles collected from Barakula were released inside the cages and maintained for over a year on these potted plants where they completed two generations.

As the beetles laid eggs on the leaf-like phyllodes, we placed an ink numeral beside each egg. Plants were inspected semi-regularly to follow development of eggs and subsequent larvae. Larval mines were measured by recording

Figs 2–4. Habitat and host plant, *Acacia crassa* Pedley (Fabaceae), for *Notosacantha dorsalis* (Waterhouse, 1877) in Barakula State Forest, Queensland, Australia: (2) habitat showing open mixed-species vegetation with mature *A. crassa* tree on left; (3) young *A. crassa* plant; (4) phyllodes and inflorescence of *A. crassa*.

maximum length and width of each mine when examined. The silhouette of the larvae inside the mine could be seen by illuminating from behind by a hand-held light (Fig. 25). Length and often width of each larva were recorded when examined. Observations ceased when the larva died, was attacked by ants, or strayed when attempting to start a secondary mine. Development of 79 eggs was followed, at least partially. Some short-term observations were made on cut phyllodes held in water in the laboratory (Fig. 7).

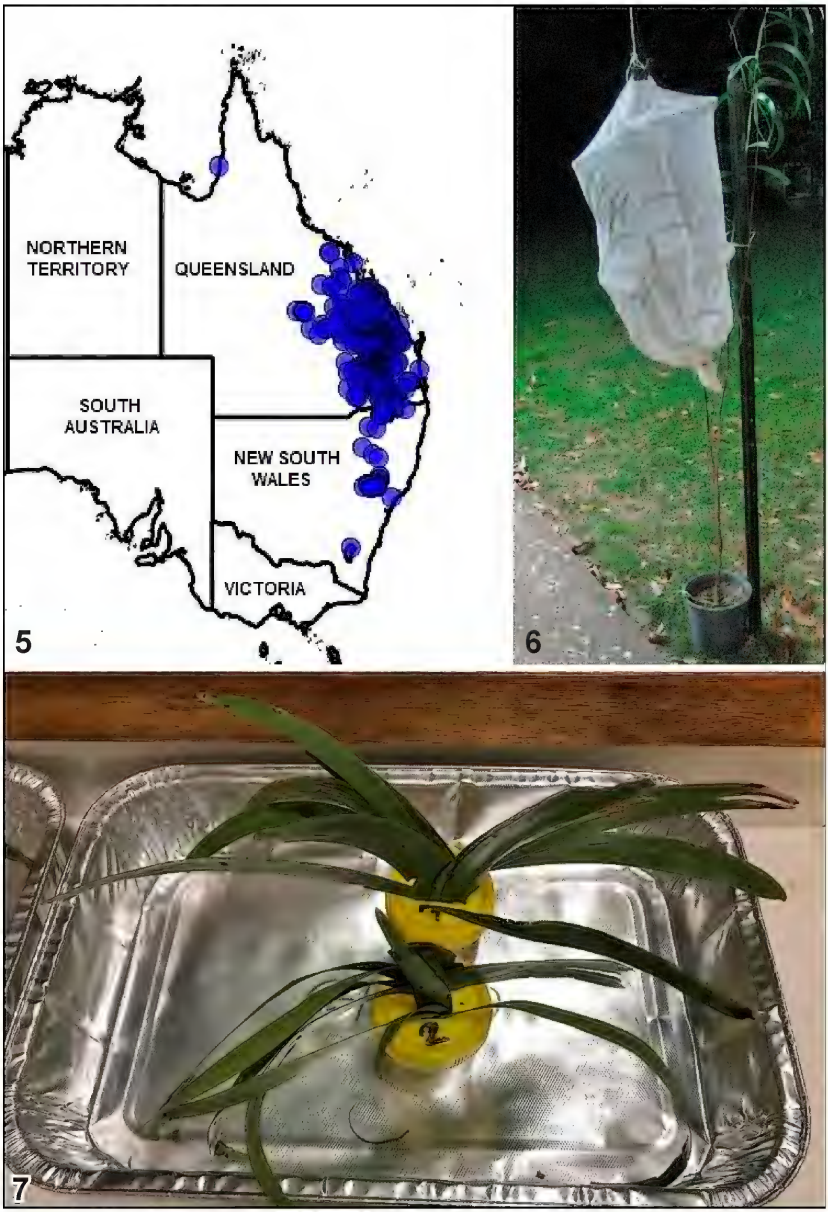
Specimens studied. Vouchers of all life history stages of *N. dorsalis* from the present study are deposited in the Queensland Museum, Brisbane, Queensland (QM) and in the University of Nebraska State Museum, Lincoln, Nebraska, USA (UNSM). Vouchers of Hymenoptera parasites are lodged in QM. A pressed voucher of *Acacia crassa* from Barakula is lodged in the Queensland Herbarium, Brisbane (BRI). Museum specimens of Australian *Notosacantha* were examined and listed by GM and VS from: Queensland Museum (132); the Australian National Insect Collection, Canberra (ANIC) (31); the Australian Museum, Sydney (AM) (4); the Museum of Victoria (MV) (1); the Queensland Dept of Agriculture and Fisheries Collection (QDAF) (12); the Museum and Art Gallery of Northern Territory, Darwin (MAGNT) (1); and the CSIRO Darwin collection, Berrimah (NTCSIRO) (2).

RESULTS

Notosacantha in Australia—species and distributions.

A summary is given here of the *Notosacantha* species recorded from Australia, based on examination of 183 specimens in Australian collections plus the few published localities in the literature indicated in our introduction. These records for the genus are mapped (Fig. 1) and show the genus is confined to Queensland and Northern Territory in the north-east sector of the continent. Clearly, formal taxonomic study is required, but there appear to be at least three, and perhaps as many as six species, in Australia. The four nominal described species below are figured in colour in the online catalog of Borowiec and Świętojańska (2012–2019).

1. ***Notosacantha dorsalis* (Waterhouse, 1877)** (Figs 1, 8–11). Most examined specimens (176 of 183) of Australian *Notosacantha* belong to this species. Published records in addition to the 'Mackenzie River' type locality are by Spaeth (1913) for 'Gayndah', 'Gawler' and 'Normantown', all of which he gives as in Queensland. Gayndah is confirmed by modern records. 'Normantown' may be an error for Normanton on the Gulf of Carpentaria beyond the known range, but it coincides with an outlier herbarium record for the foodplant (Fig. 5) and may be correct but needs confirmation. The only Australian 'Gawler' place name is in South Australia, well beyond the possible range, so we do not accept this record. The overall distribution of *N. dorsalis* is close to that of its confirmed foodplant *A. crassa* (Fig. 5). Reliable modern specimen records for *N. dorsalis* near Mt. Garnet and Charters Towers



Figs 5–7. *Acacia crassa* Pedley: (5) map of distribution in Australia downloaded from Australian Virtual Herbarium website; (6) transplanted, potted plant in Brisbane with breeding beetles in netting bag; (7) cut phyllodes in water for short-term observations. Larvae lived for some time in such phyllodes.

are beyond the plant's range and *N. dorsalis* may have a different food plant at these places.

2. ***Notosacantha monilicornis* (Spaeth, 1913)** (Fig. 1) was described with the locality unspecified, simply 'Austral. boreal.' (=northern Australia). Only four specimens are in Australian museums. The locality from King River, on the northern coast of the Northern Territory, of a 1916 specimen in MV by a reliable collector, is supported by three modern specimens in MAGNT and NTCSIRO from nearby Kakadu National Park. It differs from *N. dorsalis* in having lower elytral tubercles and only one pair of radial bars extending to margin of elytra.

3. *Notosacantha blanda* (Spaeth, 1932) (Fig. 1) was described from 'Kuranda, Queensland' and resembles *N. monilicornis*. Kuranda is now well collected, but specimens of this species have not been recollected there. Much insect material was sold to European collectors and museums by F.P. Dodd who lived in Kuranda from 1904 to 1936. He and his sons collected widely across tropical Australia and New Guinea; it is known that specimens from elsewhere often became labelled 'Kuranda, Queensland' (Monteith, 1991b). The status of this species remains in doubt, and it may be the same as *N. monilicornis* and/or *Notosacantha* sp. B (see below).

4. ***Notosacantha molucana* (Boheman, 1850)** (Fig. 1) is a uniformly black species described from Maluku in Indonesia and is also recorded from New Guinea and 'Cap. York' by Spaeth (1913). It has not been retaken in Australia. Cape York (-10.690°S X 142.532°E) is the northern tip of Australia, only 150 km from New Guinea. In the late 1800s there was an early settlement near Cape York from which early explorers and collectors visited New Guinea. Many shipments of New Guinea specimens were consigned to Europe from there and were often given the provenance of 'Cape York' (Monteith and Dewhurst 2011). There are several other uniformly black species known from New Guinea (Borowiec and Świętojańska 2012–2019). Until confirmed by further collecting, *N. molucana* remains doubtfully Australian.

5. ***Notosacantha* sp. A.** (Fig. 1). In ANIC are two adult specimens collected at Mt Tozer, Iron Range (-12.725°S X 143.284°E) in July 1986 by reliable coleopterists, T. Weir and A. Calder. Adults are distinct, pale with a crescentic dark band across the posterior half of the elytra, and do not resemble any of the many species illustrated by Borowiec and Świętojańska (2012–2019); they are likely to represent a new species.

6. *Notosacantha* sp. B. (Fig. 1). The QM collection has a single adult specimen collected at Bamaga (-10.886°S X 142. 329°E) in January 1984 by the reliable collector, J. Sedlacek. The specimen closely resembles *N. blanda* and *N. monilicornis* and suggests that there is perhaps just a single species shared across the northern part of Northern Territory and Cape York Peninsula. If this is so, then the name, *Notosacantha monilicornis,* would take priority.

Figs 8–11. Adults of *Notosacantha dorsalis*: (8) linear grooves made by feeding adult with ootheca in centre of phyllode at top; (9) detail of adult with feeding grooves placed between parallel veins of phyllode; (10) oblique view of adult showing elytral tubercles; (11) mating pair.

Natural history of *Notoscantha dorsalis* (Waterhouse, 1877)

Host plant (Figs 2–6). Beside our main study sites near the Barakula Forest Station, other sites where the beetle has been taken on *Acacia crassa*, as sightings or specimen records in QM, are: Braemar State Forest, -27.188°S X 150.785°E, GM, 4.iv.1996 & 15.iii.1980; Braemar SF, -27.204°S X 150.766°E, GM, 15–19.x.1979; Rockwood Station, -26.714°S X 150.534°E, GM, 18.viii.1984; Barakula, -26.433°S X 150.504°E, GM & VS, 2018; VS, 5.ix.2021; Barakula, -26.435°S X 150.521°E, GM & VS, 2018; Waterton State Forest, -25.370°S X 149.869°E, GM & VS, 2019; Condamine State Forest, -26.903°S X 150.305°E, GM &VS, Oct, 2019.

The QDAF collection has six adults from Calderdale, -24.860°S X 146.950°E, 8.vi.2000, G. Pegg & D. Spolc, with label data "*Acacia bancroftiorum* Maiden". The ANIC has a very old specimen with the label "collected on *Acacia penninervis*" and no locality. Both these *Acacia* species occur at Barakula, but we did not observe the beetle on them. Both are phyllodinous species (Lithgow 1997) but are not closely related to *A. crassa* and their phyllodes have very different venation and texture from that of *A. crassa*. These putative hosts both need confirmation as a host plant that supports breeding in *Notosacantha*.

Acacia crassa is native to inland, eastern Australia where it occupies a range which is roughly concordant with the Brigalow Belt Biogeographic Region (Thackway

and Creswell 1995) though it reaches the coast in the northern part of its range. Its distribution is shown here from the Australian Virtual Herbarium data (Fig. 5). It grows as a small tree reaching about 10 m. Seedlings germinate readily in disturbed areas. At Barakula it is a common understory tree on sandy soils and young plants are numerous as roadside regrowth (Figs 2–4). It is phyllodinous, as apparent leaves are expanded leaf-like petioles known as phyllodes (Figs 4, 7). Developing phyllodes at apex of branchlets have apical and basal nectary glands (Lithgow 1997) which attract ants during early phyllode development. Mature phyllodes are crescentic and average about 15 cm by 2 cm in size; each surface of the phyllode is identical. Their lamina is comparatively thick (hence the name *crassa*) with tough parallel veins within the tissue spaced about 0.5 mm apart. Usually, three of the veins are thicker than the others (Figs 18, 19). *Notosacantha dorsalis* favours juvenile plants and was rarely seen on plants taller than 3 m.

The distribution of *A. crassa* is roughly the same as that of *Notosacantha dorsalis* in the southern part of the beetle's range. However, the plant does not extend north to the Charters Towers and Mount Garnet region where we have recent records for the beetle (cf. Figs 1, 5); thus, we predict the beetle has another host plant there.

Adults and adult feeding (Figs 8–11). Adults can be found on the foliage almost year-round, except though the second half of winter (July–August) which is also the driest part of the year. We presume adults overwinter in concealed sites such as under bark and in litter during this period. During rearing in Brisbane pupae and eggs did not overwinter which supports the idea that adults are the usual over-wintering stage. Mating takes place on the phyllode surface (Fig. 11) and is facilitated by the adults' ability to cling very strongly to the surface with their expanded tarsi.

Adults of *N. dorsalis* have lengths of 4.2–5.0 mm and widths of 3.3–3.8 mm and cling tightly to the phyllode surface when disturbed. They resemble discoloured patches on the phyllodes, which are often caused by their own larval mining. Males and females are similar in appearance and there is no obvious morphological difference which allows easy sexing of adults, however, males are normally a little smaller than females. Both males and females have 11-segmented antennae, contrary to that observed in other species which usually have 10 segments in the female (Borowiec and Takizawa 1991).

Adults feed on surface of the phyllodes by taking bites of the surface cuticle and the underlying juicy epidermal and mesophyll cells with their sharp, straight-edged mandibles as they move slowly forward or backward. Bites are made between the hard parallel veins; this progressively produces a straight, shallow, linear groove in the phyllode surface which may extend for 10–20 mm in a straight line (Figs 8, 9). The feeding beetle then reverses direction and makes a new feeding groove between an adjacent pair of veins. This process results in irregular patches of several closely parallel feeding grooves. The grooves soon turn brown on the

Figs 12–17. Oothecae of *Notosacantha dorsalis* and egg parasitoid, *Asecodes* sp (Eulophidae): (12) freshly deposited faecal ootheca on centre of phyllode; (13) detail of ootheca showing fragments of undigested cuticle; (14) ootheca lifted off egg, showing collaterial gland sheath deposited over egg before faecal layer added; (15) incipient mine beside ootheca opened to show newly hatched larva; (16) ootheca lifted and egg removed to show collaterial gland sheath above and below egg position; (17) egg parasitoid pupa removed from inverted ootheca. Key to lettering: **a**, cavity chewed in leaf surface by female for reception of ootheca; **b**, lifted and inverted faecal ootheca case; **c**, collaterial gland sheath deposited over egg; **d**, remains of egg shell left by parasitoid; **e**, egg; **f**, pupa of egg parasitoid, *Asecodes* sp.

green background resulting in a distinctive appearance (Fig. 20) which is good indication that beetles are present on a plant. Adult feeding penetrates less than half the depth of the phyllode, so it is possible for adult feeding to take place on the opposite phyllode surface to areas that have already been browsed. Adult feeding inhibits later larval feeding mines from extending inside the leaf through

the same area (Fig. 20). Adult feeding is usually concentrated into patches of closely adjacent grooves, which seems to leave much of the phyllode available for subsequent larval mines.

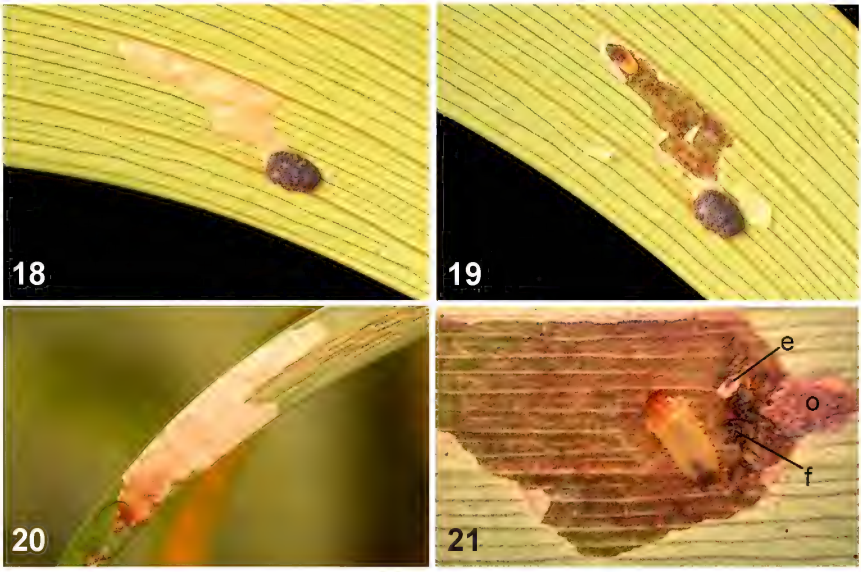
Eggs and egg-laying (Figs 12–19). Eggs are elongate-ovate, pale yellow in colour and measure about 1.5 x 0.7 mm (Fig. 14). These are laid singly on the phyllode and always close to its centre (Fig. 12). The eggs may be laid on both sides of one phyllode, but it is rare for more than two eggs to be laid on any one side. We noted one example of four eggs on one phyllode, all being separated by at least 20 mm.

Before ovipositing, the female bites a short, deep cavity ca. 2.0 x 1.5 mm into the phyllode surface (Figs 14, 16, 17). She then deposits a single egg into the cavity and covers it with a thick, opaque sheath, presumably a secretion of the collaterial glands. The sheath material seals to the edge of cavity all around but does not adhere to the egg surface (Figs 14, 16, 17). Occasionally the sheath material extends beneath the egg (Fig. 16). The female then deposits a pile of faeces that covers and surrounds the egg cavity and adheres to the glandular sheath. The female then presses her abdomen to flatten the faecal deposit. The final composite structure is termed an ootheca.

Microscopic examination of the surface shows that the faecal mass is composed of numerous squares of un-digested leaf cuticle, each representing a feeding 'bite' by the adult (Fig. 13). These cuticle pieces are embedded in a hard black material and often form a 'tiled' surface to the ootheca. The faecal material dehydrates to a hard, tough protective capsule for the egg. The long axis of the ootheca is always parallel to the long axis of the leaf (Fig. 12). Oothecae are about 2.5 mm long and 1.5 mm wide. Attachment of oothecae to the phyllode is very strong and these remain in place, even after hatching, for the life of the phyllode.

Egg duration, hatching and mine initiation (Figs 15, 18, 19). We followed the fate of 38 eggs which hatched and determined the average duration of egg stage to be 13.4 days (range 9–24 days). The egg is not visible, so hatching was determined as when the larva commenced a visible mine beside the egg capsule. Sometimes this may postdate actual hatching by a few days. We saw no evidence of delayed hatching as a hibernation device.

Since the egg is sunken in the leaf cavity made by the female in the phyllode tissue, the neonate larva can feed its way directly ahead, exit the egg chamber below the level of the hard faecal deposit, and enter the subsurface phyllode parenchyma tissue beneath the tough cuticle which remains intact as a transparent roof over the nascent mine chamber (Figs 15, 18). The mine chamber is connected to the empty oothecal chamber but not to the outside environment. This mine is rapidly enlarged by feeding in one direction, away from the empty ootheca which remains contiguous with the mine perimeter. Within a few days, the new larval mine may have a diameter of 3–5 mm. We term this first larval mine the 'primary mine', as defined below.



Figs 18–21. Primary larval mines of *Notosacantha dorsalis*: (18) newly hatched ootheca with small initial mine made by first instar emanating from capsule. Note early mine does not cross major veins; (19) same mine as in 18 opened to show first instar larva; (20) large primary mine emanating from ootheca at left. Note mine crosses major and minor veins but does not cross old adult feeding groves; (21) opened primary mine to show frass heap of faecal pellets (f) and exuviae (e) deposited by larva adjacent to ootheca (o). Note raised ribs of veins across floor of mine exposed by larval feeding.

Primary mines (Figs 15, 18–21). The primary mine is that made by the neonate larva once it ecloses. This mine is roofed by the transparent cuticle, has no opening to the exterior (it is closed) and has the hatched ootheca contiguous at one side. The cuticle bulges upward a little, giving the larva room to move freely within the mine. The larva extends the mine by feeding on sub-cuticular tissues at the edges of the mine. This is done by pushing and biting under the edge of the cuticle with its flat wedge-shaped head and prognathous mandibles (Fig. 26). The mine is extended in random directions across and along the phyllode, often towards both apex and base of the phyllode from the initial egg hatching site.

Mines never extend beneath previous feeding marks of adults on the phyllode surface (Fig. 20). We measured many mines and found the largest mines to have maximum length 100mm and maximum width of 20 mm. If two eggs are laid on one phyllode surface, then the two separate mines that develop from them sometimes merge; a merged mine may thus be occupied for a short time by two larvae. This is the only time we observed interactions between these solitary larvae. Two such larvae in one merged mine were never seen to both reach maturity suggesting some aggression/predation between the two larvae within such merged mines.

Rarely, the larva grows to full size and eventually pupates inside the primary mine.

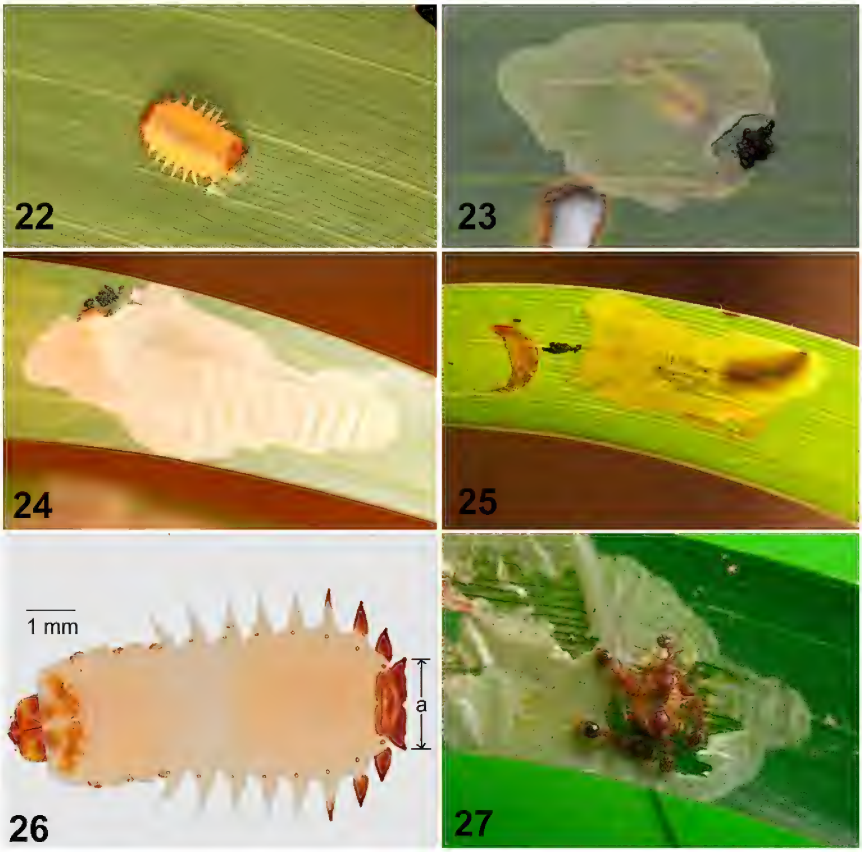
More commonly, the III–IV instars exit the primary mine and constructs what we term a 'secondary mine' as defined below.

Secondary mines (Figs 22–25, 28, 29). When the larva in a primary mine has exhausted areas of the original phyllode into which it can extend that mine, it exits the mine by cutting a slit in the cuticle, travels along the phyllode and stem surface, and then enters another phyllode surface. This may be on the opposite side of the original phyllode, on an adjacent phyllode, or sometimes several phyllodes further along the same stem. Such new mines have a permanent, crescentic opening and are termed 'secondary mines'.

In our observations, secondary mines were always initiated at night when we presume the exposed, travelling larva was safer from predation (this was also presumed for other night-time crossing larvae in Ford and Cavey (1985)). We tested this ability to make new mines by removing several late-stage larvae from existing mines (in our garden plants) and enclosing them with cut phyllodes in petri dishes where they made new mines within about 30 minutes. The larva initiates the secondary mine by griping the phyllode surface with tarsal claws, then swinging the head in a short arc from one side to the other, biting a curved incision 4–5mm long into the cuticle as it does so (Fig. 22). It then repeats the movement, biting into the epidermal cells beneath the cuticle and pushing further under the cuticle with its flat, wedge-shaped head. As this is repeated the cuticle progressively lifts and the larva pushes further and further under the cuticle until it is completely within an incipient mine with the distinctive arc-shaped entrance (Figs 23–25) that is characteristic of a secondary mine. The larva then continues to feed on the soft tissue and enlarges the mine as it did earlier in the primary mine.

In some cases, in our reared stock on potted plants, we observed larvae making a second secondary mine after they had exhausted available feeding area in the first mine. In one case, a single larva made three secondary mines in sequence, on three different leaves.

Larval behaviour within the mine: feeding, defaecation and moulting (Figs 21, 23–25). Within the mine the larva cuts through the upper part of the hard veins, freeing the cuticle above so that it lifts above the tissue surface. The larva then feeds on the soft tissue between the closely spaced, hard veins beneath it. This gradually exposes the veins as a series of raised ridges across the floor of the mine (Fig. 21). However, the mandibles functionally can only reach a short distance into the cleft between the veins, so only the upper layer of soft-tissue cells is consumed. Feeding is so shallow that two larvae can form separate mines on opposite sides of the same portion of a phyllode without the two mines becoming connected, while the stiff veins maintain the structural shape of the phyllode.



Figs 22–27. *Notosacantha* mature larva in secondary mines: (22) late instar larva commencing a secondary mine; (23) secondary mine showing wide, arc-shaped entrance where larva entered. Larva visible through cuticle roof of mine. Note larval faeces deposited outside entrance of secondary mines; (24) secondary mine with larva protruding rear end out entrance to deposit faeces; (25) backlit feeding larva in secondary mine, with faeces outside arc-shaped entrance. Larval gut is full and evacuated before pupation. Note on left abandoned first attempt by larva to commence mine; (26) last instar larva showing measurement of anal plate used for instar determination, photo © Queensland Museum; (27) *Tetramorium bicarinatum* ants killing a larva after tearing open the mine.

Young larvae in primary mines, during instars I–II, always deposit their faecal pellets by pushing them into a compact deposit against the opening into the empty ootheca (Fig. 21). This dries to a hard, black, shiny deposit. When the larva begins to moult, exuviae I and II are also pushed into this refuse pile and become covered by subsequent faecal deposits. From instar III onwards the faeces and exuviae are usually just deposited in the centre of the closed primary mine.

After the larva leaves the primary mine and enters a secondary mine, it then always deposits faeces and exuviae on the phyllode surface outside the opening of the secondary mine (Figs 23–25).

Duration of larval life. During breeding on potted plants in Brisbane we recorded four larvae which grew from egg hatching to pupation. The growth periods from egg hatching to pupation were 20 (26 Nov.–15 Dec.), 24 (13 Dec.–16 Jan.), 35 (5 Dec.–9 Jan.), and 36 days (5 Jan.–10 Feb.). These give an average of 29 days (range of 20–36 days). All occurred during the Australian mid-summer. We observed breeding well into early winter in the field, but we have no data on the larval durations at that time.

Pupation (Figs 28, 29). The prepupal larva is instar IV (see determination of instar number below). In secondary mines it always adopted a quiescent position just inside the arc-shaped mine entrance, with the head of the larva directed towards the entrance. During this period of a few days, the dark stomach contents, which could be seen at the centre of the larva by using a backlight (Fig. 25), were evacuated. Shortly afterwards, the pupal moult occurred; as the moult ended, twitching forward and backward pupal movements always ejected exuviae IV through the mine entrance. In our garden cultures, the pupal period, from moult to adult emergence ranged from 8–15 days in 8 observed individuals and averaged 12 days. There was no evidence of delayed adult emergence as an overwintering strategy. In early spring (5 Sept 2021) author VS found mature adults feeding, mating and laying eggs on foliage, with no sign of recent pupal mines on leaves. It is assumed these adults had spent winter in concealed hibernation.

Adult emergence (Fig. 29). The pupa rests inside the secondary mine with head towards the mine entrance**.** As the adult beetle emerges from the pupa it drags itself outside the entrance of the mine and the pupal exuviae is usually finally shed on the surface of the leaf, falling away. Only rarely does the pupal exuviae remain inside the mine. This is unlike some other hispines where the teneral adult remains in the mine, avoiding predators while the body hardens (Ford and Cavey 1985). The adult begins to feed on the leaf surface within 1–2 days of emergence.

Number of instars (Figs 26, 30). Since *Notosacantha* larvae live in a mine it is not possible to directly observe moulting. We determined the number of instars in *N. dorsalis* by two indirect methods: (1) measurement frequency of a standard body part, and (2) counting of exuviae discarded in mines.

(1) Measurement frequency. Head width is usually used for plotting a measurement frequency to determine larval number in insects under the Brooks-Dyar Rule (e.g., Floater 1996) and was applied for *Pentispa* (Cassidinae: Chalepini; Boldt and Staines 1993). We did not have a large enough sample of all instars of whole larvae to undertake this, so we used measurements of the maximum width of the heavily sclerotized last (ninth) abdominal tergum (anal plate) instead (Fig. 26). The anal plate is preserved intact in larval exuviae, of which we were able to obtain many from inside mines (Fig. 21). The width distribution of the 128

Figs 28, 29. Pupation and adult emergence of *Notosacantha dorsalis*: (28) opened secondary mine showing pupa shedding larval exuviae near mine entrance; (29) adult beetle shortly after emerging from the pupal exuviae outside the arc-shaped entrance of its secondary larval mine.

individual measurements obtained is shown in Fig. 30 where each bar represents the number of individuals which fall within an 0.04 mm size class. This clearly shows four size groups corresponding to instars. Figures indicate that ~95% of larvae fall into one of the following anal plate size classes: instar I (0.34–0.42 mm), instar II (0.60–0.70 mm), instar III (1.00–1.10 mm), instar IV (1.60–1.80 mm). This simple measurement provides some confidence to determine the instar of larvae.

(2) Exuvial number. Since exuviae of larvae in primary mines remain in the closed mine, usually embedded in the faecal mass, it was possible to carefully extract them from the faecal pile (Fig. 21) and arrange in sequence of size. We were never able to find more than three exuviae in the primary mine. We carefully observed the large larvae in their secondary mines. Those that had vacated their primary mine, leaving three exuviae behind, never moulted again more than once in their secondary mine. From this we arrived at the number of four larval stadia which accords with the results obtained from anal plate frequency measurement.

Predators of *Notosacantha dorsalis* (Fig. 27). During rearing of *N. dorsalis* in Brisbane, larvae and pupae inside the mines were often attacked and killed by the introduced ant *Tetramorium bicarinatum* (Nylander, 1846). This ant is a soil-nesting, semi-cosmopolitan, stinging species that has been introduced to Australia from its original distribution in S. E. Asia (Burwell, 2007). The ants tore open the surface membrane of the mine (Fig. 27), envenomated the larva or pupa, dismembered the body and carried it off. Although this ant is not established in natural environments in Australia, we assume that other native predatory ants may attack *Notosacantha* mines in the field, though we did not observe this.

Parasitoids of *Notosacantha dorsalis* (Figs 16, 17). Hymenopteran parasites of both egg and larval stage were detected in *N. dorsalis*. A larval parasite was taken on only one occasion, but in numbers, and the specimens have been identified as an undescribed species of *Notanisomorphella* Girault, 1913 (Hymenoptera: Eulophidae; Chris Burwell, *pers. comm.*). Thirty-one primary larval mines were collected by GM at Braemar State Forest, 15 March 1980. When opened, 15 of

the mines contained dead beetle larvae plus pupae, pupal exuviae and/or adults of the wasp parasitoid. The parasitoid larvae had emerged from a single hole in the venter of the beetle larvae and numbered from 1–6 (mean 2.4) per host larva. The parasite larvae pupate free in the mine with the pupa connected by its shed exuviae to a congealed drop of prepupal faeces on the floor of the mine. Where the emerged wasps had exited the mine, there was a circular chewed hole in the roof of the nine. Nine male and 20 female adult wasps were recovered from the mines. Since they were all closed primary mines it is assumed that female wasps oviposited into the beetle larva through the roof membrane of the mine.

The egg parasite was detected twice. Of 11 egg oothecae collected at Barakula by GM on 10 June 2018, six contained viable eggs while five had remains of the pupae of an unknown microhymenopteran (Hymenoptera) which had consumed the egg. Very recently VS collected 20 egg oothecae at Barakula on 5 Sept 2021. Six of these contained pupae of the same parasitoid (Fig. 17), two of which hatched on 20 and 21 September to a 1.0 mm slender metallic green wasp now identified as a species of *Asecodes* Förster, 1856 (Eulophidae: Entedontinae) by Dr Chris Burwell. He advises that the biology of the species in the genus is varied, with hosts including Diptera (especially Agromyzidae), Lepidoptera and Coleoptera. They are parasitoids of egg, larvae and pupae; some are parasitoids of Chrysomelidae eggs, including hispines (Burwell, *pers. comm.*). It is difficult to conceive such a small wasp, lacking a long ovipositor, penetrating the oothecal defence of the *Notosacantha* egg. Being very small, it may oviposit by stealth during the actual egg laying process.

The field infestation rate for both the above parasitoids was quite high in the collected field samples. Neither was encountered in two years of rearing *Notosacantha dorsalis* in open situations in Brisbane which is outside the natural range of the beetle. Ant predators and Hymenoptera parasitoids are common enemies of Cassidinae (Cox 1994, 1996).

Discussion

Our study of *N. dorsalis* revealed many features relevant to species variations in *Notosacantha* and to broader patterns, including existing and potential character hypotheses, that could strengthen the systematics of the genus and tribe within Cassidinae. We discuss some of these below, with potential information for phylogenetic characters in Chaboo (2007: Appendix 4) for Cassidinae and in wider Chrysomelidae (Reid 1995).

Notosacantha species show a wide choice of host plants (Table 1: 12 different families to date) and it is difficult to discern any phylogenetic and or chemistry patterns across these choices. A single *Notosacantha* species can use phylogenetically diverse hosts, e.g., Sekerka (2009) reported *N. molucana* on three confirmed, unrelated hosts. Ghate *et al.* (2003) remarked "Both the species of *Notosacantha* prefer plants with somewhat thicker, smooth surface leaves." Our observations concur with selection of thicker, smooth leaves.

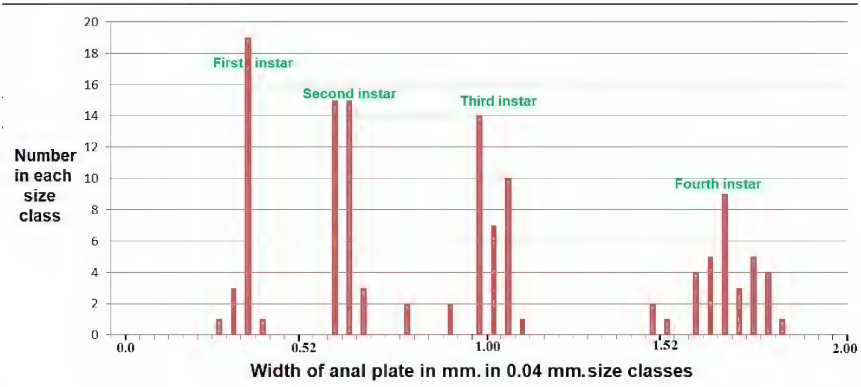


Fig. 30. Plot of size frequency of widths of measured anal plates of 128 larvae of *Notosacantha dorsalis* used to determine number of instars. Each bar represents number of anal plate widths in that size class.

Our observations revealed solitary, sessile eggs attached within a groove chewed out by the female (Characters 0–1 of Chaboo 2007; Character 48 of Reid 1995). This maternal behaviour of preparing the groove is similar to that reported for *N. siamensis* (Medvedev and Eroskhini (1988) and resembles reports for cassidine genera (e.g., Chalepini: *Pentispa* Chapuis, 1875 by Boldt and Staines 1993; Coelaenomenoderini: *Javeta* Baly, 1858 by Shameem *et al.* 2016; Hispini: *Platypria* Guérin-Méneville, 1840 by Ranade *et al.* 2021). It may be widespread in Cassidinae and could offer a novel phylogenetic character. Another potentially novel character is the maternal behavior of covering the egg, resembling that in some other cassidines (e.g., Chalepini by Boldt and Staines 1993; Promecothecini by Taylor 1937). The female's effort to cover and flatten the faecal pile is reminiscent even of Camptosomata leaf beetles whose females may spend up to one hour carefully creating the protective coating of single eggs (Brown and Funk 2005). The material covering the egg is significant since some females of mining Cassidinae secrete a fluid that hardens into an ootheca (e.g., *Javeta, Platypria*) whereas others regurgitate leaf fibres (*Coelaenomenodera* Blanchard, 1853) (Shameem *et al.* 2016). Multi-layered membranous oothecal coverings also occur in some tortoise beetles (e.g., *Aspidimorpha miliaris* (Fabricius, 1775) produces very complex ootheca; Maulik 1919). Some elaborate oothecae may be further covered with faecal deposits (Verma and Kailachelvan 2004). Thus, there is rich diversity in Cassidinae maternal behaviors at oviposition.

Cassidinae larvae display a remarkable variation in the number of instars, ranging from two in *Promecotheca cumingii* Baly, 1858 (Maulik 1919) to nine in *Alurnus humeralis* Rosenberg, 1898 (Villacis Santos 1968). Our determination of the number of four instars may be the most comprehensive done for any Cassidinae. This may be the norm in Notosacanthini, Coelaenomenoderini, Hispoleptini, and

Table 1: Recorded foodplants of *Notosacantha* (see Borowiec and Świętojańska 2012–2019 for original sources) updated with additional records (marked by *) from Borowiec and Takizawa (1991) and this paper.

NOTOSCANATHA SPECIES	PLANT SPECIES	PLANT FAMILY	REGION
Notosacantha badia (Boheman, 1850)	*Gymnosporia mossambicensis* (Klotsch) Loes.	Celastraceae	South Africa
Notosacantha calligera (Spaeth, 1921)	*Gironiera* sp. *Knema* sp.	Myrsinaceae	Borneo
Notosacantha dammaropsi Sekerka, 2009	*Ficus dammaropsis* Diels	Moraceae	New Guinea
Notosacantha diabolica Świętojańska, 2001	*Ardisia* sp. *Embelia* sp.	Myrsinaceae	Borneo
Notosacantha dorsalis (Waterhouse, 1877)	*Acacia crassa* Pedley *?A. bancroftiorum* Maiden *?A. penninervis* DC	Fabaceae	Australia
Notosacantha junodi (Spaeth, 1913)	*Tarenna pavettoides* (Harv.) Sim	Rubiaceae	South Africa
Notosacantha laticollis (Boheman, 1862)	*Canthium inerme* (L.P.) Kuntze	Rubiaceae	South Africa
**Notosacantha maculipennis* (Boheman, 1850)	*Alnus* sp.	Betulaceae	India
Notosacantha molucana (Boheman, 1850)	*Decalobanthus peltatus* (L.) Simoes and Staples *Pterocarpus indicus* Willd. *Ficus variegata* Blume	Convolvulaceae Fabaceae Moraceae	Ambon, New Guinea Australia?
**Notosacantha nepalensis* Borowiec and Takizawa, 1991	*Cleyera japonica* Thunb.	Theaceae	India
Notosacantha pakistanica Sultan *et al*, 2008	*Alnus nitida* (Spach) Endl.	Betulaceae	Pakistan
Notosacantha quadra (Spaeth, 1915)	*Ardisia elliptica* Thunb.	Myrsinaceae	Borneo
Notosacantha severini (Spaeth, 1913)	*Carissa carandas* L.	Apocynaceae	India, Thailand
Notosacantha siamensis (Spaeth, 1933)	*Phyllanthus emblica* L.	Euphorbiaceae	Thailand Vietnam
Notosacantha tenuicula (Spaeth, 1913)	*Cleyera japonica* Thunb.	Theaceae	India, Nepal
Notosacantha vicaria (Spaeth, 1913)	*Glochidion ellipticum* Wight *Carallia brachiata* (Lour.) Merr.	Euphorbiaceae Rhizophoraceae	India Sri Lanka

some Hispini (see Chaboo 2007:45). It is unclear if contracting and speeding the life cycle avoids enemy pressure.

Taylor (1937), using the synonym *Promecotheca reichei* Baly, 1869 for *Promecotheca caeruleipennis* Blanchard, 1853, pointed out that the mining neonate larva chews forward from the egg, so the leaf in front of the egg must be long enough to accommodate larval consumption and growth. Our observations confirm that the neonate *Notosacantha* initially chew forwards from the egg, but since the egg is always placed in the centre of the leaf, and since an irregular blotch mine is formed, there is always room for the mine to later expand in any direction.

The ability of the *N. dorsalis* leaf-mining larva to exit the initial mine and to re-enter the leaf at a different site has been documented for other *Notosacantha* species in India (Rane *et al.* 2000; Ghate *et al.* 2003; Ghate 2004), South Africa (Heron 2018), and Vietnam (Medvedev and Eroshkina 1988). Medevdev and Eroskhina (1988) termed the initial mine a 'trophic mine'. In those other *Notosacantha* species, the secondary mine or 'pupal mine' is made only at the end of larval life; no substantial feeding takes place in the new mine and it is made just big enough to accommodate the pupa. In *N. dorsalis,* however, the first secondary mine is usually made well before the end of larval growth, may be enlarged considerably by feeding to become as large as the primary mine, and this enlarged secondary mine serves for pupation.

Of the larval exit from a primary mine, Medvedev and Eroshkina (1988) write (translation): 'So they cut at one end, and crawl out backwards. The end is obviously cut by the posterior shovel, but we did not observe it.' By 'posterior shovel' they refer to the sclerotized and toothed anal plate (Fig. 26). Our breeding larvae often exited primary mines through a cut slit, always at night, and we also did not observe this process. However, we often observed larvae cutting slits for entry into new mines (Fig. 22) and their chisel-shaped head and cutting mandibles are the efficient tools used in this process. We suggest that it is not necessary to speculate that the anal plate is used to make exit slits when the mandibles are available. From our observations we believe the sclerotized and toothed structures at the anal end of the larvae function to grip the surface of the substrate to aid in pushing the body forward during forward locomotion, especially when inside the mine.

Chrysomelid larval morphology strongly reflects their life as leaf miners, cryptic feeders, or open feeders (Reid 1995) and this applies to *Notosacantha* larvae with their dorso-ventral flattening and wedge-shaped, knife-edged head. We will address specific features, patterns and characters in a future study on morphology of mining larvae.

Few characters have been developed and tested for chrysomelid pupae (Reid 1995). Chaboo (2007) offered just two characters for Cassidinae and López-Pérez *et al.* (2021) proposed 10 new ones. Nevertheless, as more Cassidinae pupae are

being collected and described, this life stage could potentially offer a novel suite of characters to inform phylogeny resolution. The pupation site and morphology of *Notosacantha* pupae are promising avenues for future exploration.

Conclusions. Not long ago, Borowiec and Świętojańska (2014b:199) considered "Life cycles of Cassidinae are generally poorly known and concern mostly Holarctic species." As more species are studied world-wide, particularly those with leaf mining life cycles, we are uncovering rich information to determine novel patterns, unique traits, and new character hypotheses for taxonomic and evolutionary assessment. Our study of museum specimens here suggests more diversity in the adults of *Notosacantha* in Australia so clearly more collecting and morphological study are needed. These species will be examined further as we focus next on the morphology of the life stages of *N. dorsalis*. Our study converges with the review of Bornean *Notosacantha* (Borowiec *et al.* 2013) and of Indian *Notosacantha* (Hari and Prathapan, unpublished data) and altogether will unravel further the biology and systematics of this ancient and evolutionarily enigmatic tribe of Cassidinae.

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REDESCRIPTION OF *PSALTODA FUMIPENNIS* ASHTON, 1912 AND DESCRIPTION OF A NEW ALLIED SPECIES FROM THE QUEENSLAND WET TROPICS (HEMIPTERA: CICADIDAE: CICADINAE)

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Abstract

We redescribe the cicada *Psaltoda fumipennis* Ashton, and designate a neotype for the species from northern Queensland, Australia. *Psaltoda seismella* **sp. n.**, a species closely allied to *P. fumipennis*, and also from northern Queensland, is newly described. First documentation of the distinctive calling songs of both species is provided. The geographical distribution and overlap zone of the two species within the Wet Tropics region is discussed, especially in relation to the Black Mountain Corridor.

Key words: cicada songs, Cicadoidea, Auchenorrhyncha, biogeography, taxonomy

Introduction

The genus *Psaltoda* Stål, 1861 contains 15 described species, which are found in coastal and inland areas of eastern Australia (Moulds 2012). *Psaltoda fumipennis* Ashton, 1912 is a distinctive cicada, restricted to the Wet Tropics in northern Queensland (Moulds 1990). Close examination of specimens of *Psaltoda fumipennis* and their calling songs has revealed that it represents two species, with a small area of overlap in distribution. Here we provide a morphological redescription of *Psaltoda fumipennis* and a description of the new species, along with their calling songs and a discussion on their ecology and distributional limits, species limits and biogeography.

Abbreviations for collections are: AM—Australian Museum, Sydney; ANIC—Australian National Insect Collection, CSIRO, Canberra; DE—private collection of D.L. Emery, Sydney; LWP—private collection of L.W. Popple, Cairns; MSM—private collection of M.S. Moulds, Kuranda; QM—Queensland Museum, Brisbane; SAM—South Australian Museum, Adelaide. For name-bearing types, label data are quoted verbatim. For all other material, label data are transcribed with month of collection presented in Roman numerals.

Morphological terminology follows Moulds (2005, 2012). Terminology for calling songs is adapted from Ragge and Reynolds (1998). The term "pulse" refers to the shortest duration unit of sound observed to be produced by these cicadas and is produced by a single activation of a timbal (or left and right timbals in synchrony). A grouping of pulses is referred to as a "syllable". A higher order grouping of syllables is referred to as an "echeme". Calling song analysis and visualisation was performed using Adobe Audition software.

Tribe Psaltodini Moulds, 2018
Genus *Psaltoda* Stål, 1861
Psaltoda fumipennis Ashton, 1912
(Figs 1–10)

Neotype designation and clarity of type locality. The original description by Ashton (1912) is as follows. "♂ Head, pronotum and mesonotum olivaceous-green. Head with eyes black, front and broad fascia across vertex, black. Pronotum with anterior margin, sulci, anterior border of posterior margin and spot on anterior angles of lateral margins, black. Mesonotum with two anterior central inwardly curved fasciae, between which is a fine longitudinal median fascia, and outside of which, on each side, is a small obconical anterior spot, and a series of four small spots along the anterior concavity of cruciform elevation, black. Abdomen brownish-ochraceous, anterior and posterior margin of first segment finely black, posterior margins of remaining segments fuscous. Tegmina and wings hyaline, talc-like, costa and venation fuscous, veins at bases of second and third tegminal apical areas broadly infuscate, tips of tegmina and wings strongly tinged with fuscous. Head beneath, sternum and legs, pale green, narrow fasciae between base of face and eyes black, rostrum, tibiae and tarsi brownish, opercula ochraceous, abdomen beneath luteous, translucent. Rostrum barely reaches posterior coxae. Head, including eyes, a little broader than base of mesonotum, front broad, not prominent. Abdomen above considerably longer than space between apex of front and base of cruciform elevation. Opercula obtusely rounded posteriorly, overlapping internally. *Long.*—(excl. teg.) 32 mm.; exp. teg., 86 mm. *Hab.*—Port Darwin (?). Mr. F.P. Dodd. This species may be easily recognised by fuscous tips to tegmina and wings."

In later publications (Ashton 1914, 1921), Ashton referred to Kuranda, Queensland, as the locality for the species (Moulds, 1990). As no specimens of *Psaltoda* have been collected from the Northern Territory and specimens matching the original description are confined to northern Queensland, Kuranda should be regarded as the type locality.

The whereabouts of the type specimen(s) is unknown. Type material from other taxa described by Ashton (1912) is in the AM. One of us (MSM) was Collection Manager at the AM from 1990 to 2006 during which time the specimen could not be located. There are four specimens in the SAM labelled "Kuranda Queensland F.P. Dodd". These do not bear type labels and none is considered likely to be a type; however, these specimens may have been influential in Ashton's (1914, 1921) reattribution of locality. The type specimen(s) is considered to have been lost. The *International Code of Zoological Nomenclature* 1999 states that neotypes should be designated when there is the possibility of confusion in identifying a taxon (ICZN 1999). To accommodate the description of a second species allied to *P. fumipennis* (described herein), a neotype is designated from the reassessed type locality (*i.e.* Kuranda) from recently collected material (Fig. 6).

Fig. 1. Distribution of *Psaltoda fumipennis* (open squares) and *P. seismella* sp. n. (closed stars) in the Wet Tropics, shown relative to the Black Mountain Corridor (a biogeographic barrier).

Neotype here designated: ♂, label 1 (white card): 'Australia: Qld, AU.QL.MAK / 4 Victor Place, Kuranda, / 16°48.923'S 145°38.550'E / 395m, 18 Jan. 2007, Hill / Marshall, Moulds, Humphrey'; label 2 (green card): 'C. SIMON LAB VOUCHER / legs in ETOH, body pinned / 07.AU.QL.MAK.05 / Psaltoda "fumipennis cx"'; label 3 (white card): 'K517969'; label 4 (red card): 'NEOTYPE / *Psaltoda fumipennis* / Ashton, 1912 Desig. / Popple & Moulds, 2021' (AM).

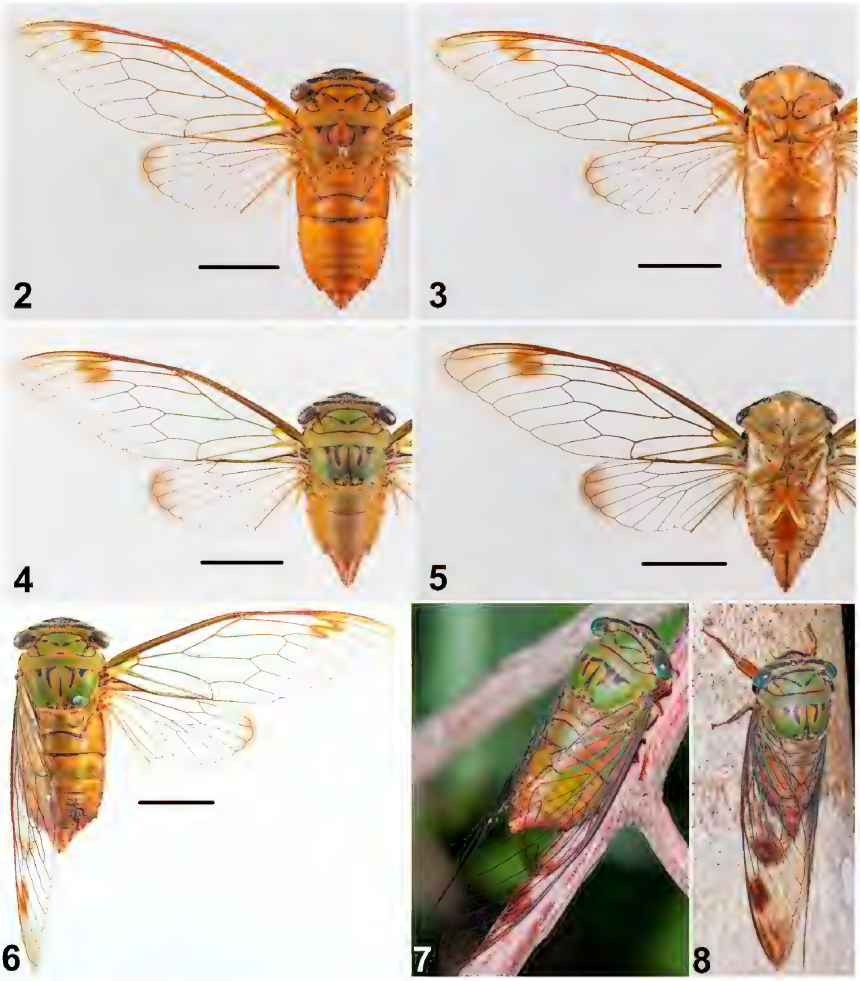
Other material examined. QUEENSLAND: 2♂♂, 2♀♀, Kuranda, F.P. Dodd, SAMA Database Nos 20-013965, 20-013966, 20-013740, 20-031741 (SAM). 1♀, 16°05'S 145°26'E, Cape Tribulation transect Site 8, 750 m, rainforest, 17-18.xi.1998, C.J. Burwell, [sample code] 50031, T235305; 1♂, Mt Lewis, 23.xii.1995, J. Hasenpusch, T235308 (QM). 1♂, Mt Lewis Rd., Julatten, 16°34′34″S 145°19′43″E, 6.i.[20]08, D. Emery & L. Popple; 1♀, Mt Lewis nr. Julatten, i.1986, S. Lamond (DE). 2♂♂, Mt Lewis foothills, 16°34′34″S 145°19′43″E, 6.i.2008, rainforest, L. Popple, D. Emery, 105-

0001 & 105-0002; 1♂, 1♀, Davies Creek Camp Node 7/8, 17°02′00″S 145°36′23″E, 30.xii.2019, wet sclerophyll, L.W. Popple, A.E. McKinnon, 105-0003 & 105-0004; 2♂♂, start of Surprise Creek track, Barron Gorge NP, 16°50′48″S 145°38′34″E, 11.i.2020, L.W. Popple, A.E. McKinnon, 105-0005 & 105-0006 (LWP). 3♂♂, 8♀♀, Mt Hartley nr Rossville, S of Cooktown, 1.i.1984, M.S & B.J. Moulds; 2♂♂, 4♀♀, Windsor Tableland, NW of Mossman, 27.xii.1976, M.S. & B.J. Moulds; 1♂, Mt Windsor Tableland, NW of Mossman, 6.i.1981, M.S. & B.J. Moulds; 1♀, Windsor Tableland, NW of Mossman, 16:14S 145:04E (GPS), 4.i.1994, M.S. & B.J. Moulds; 2♀♀, Mt Lewis, 30 km in near end of road, W of Mossman, 28.xii.1989, M.S. & B.J. Moulds; 2♀♀, Mt Lewis, 1.i.96, D. Kitchin, T. Jack; 1♂, Mt Lewis, 6.xii.1985, A&M Walford-Huggins, 36 km [in near end of road]; 2♀♀, Mt Lewis, 14.xii.1985, A&M Walford-Huggins; 1♀, Mt Lewis nr Julatten, i.1986, S. Lamond; 1♀, Mt Lewis, 16:30S 145:16E, D. Kitchin & T. Jack; 2♂♂ (1 genitalia preparation PS70), Mt Lewis, 22.xii.1985, A. & M. Walford-Huggins; 1♂, Mt Lewis road, near Mt Surgeon, W of Mossman, 25.xii.1987, M.S. & B.J. Moulds; 1♂, Mt Lewis, via Julatten, 12.i.1995, Dennis Kitchin; 1♂, Mt Lewis nr Julatten, i.1986, S. Lamond; 1♀, Mt Lewis, 16:30S 145:16E, 29.xii.1992, D. Kitchin; 1♂, Davies Ck, nr Mareeba, 650m, rainforest, 7.i.1980, A. Hiller; 2♂♂, 3♀♀, upper Davies Ck, Lamb Rg Mareeba Dist., 800m, 25.xii.1988, H. & A. Howden; 1♂, Julatten, 18.xii.1980, M.S. & B.J. Moulds, genitalia prep. [no number]; 1♀, Mt Bellenden Ker summit, alt 1,580 m, 15.xii.1976, M. Walford-Huggins; 1♂, 1♀, Bellenden Ker, 5,200', , 18.i.1978, A. & M. Walford-Huggins (MSM).

Audio recording localities. QUEENSLAND: Mt Lewis Road (upper), 16°34′01″S 145°16′21″E, 28.xii.2013; Mt Lewis foothills, 16°34′34″S 145°19′43″E, 6.i.2008; Black Mountain Road, 16°39′53″S 145°29′29″E, 6.i.2018; Kuranda National Park, 16°47′06″S 145°37′44″E, 6.i.2018; Barron Gorge National Park, 16°50′48″S 145°38′34″E, 17.iv.2021; Lake Morris Road, 16°58′31″S 145°41′54″E, 8.i.2019; Davies Creek Camp Node 7/8, 17°02′00″S 145°36′23″E, 30.xii.2019; Boar Pocket Road, 17°12′15″S 145°39′59″E, 29.ii.2020; Gillies Highway Forest Reserve, 17°12′54″S 145°41′09″E, 29.ii.2020 (LWP).

Distribution, habitat and seasonality (Fig. 1). From Mt Harley south of Cooktown and from the Mount Windsor Tableland south-south-east to Mt Bellenden Ker. It is a common species at times in the vicinity of Julatten and on Mt Lewis, in Barron Gorge National Park south of Kuranda and in Davies Creek National Park. It occurs in remnant and mature regrowth rainforest, at a range of elevations (though primarily upland), including in clearings, ecotones and in areas where rainforest is successional to wet sclerophyll forest. Adults may be common between December and March, with records extending from mid-November to mid-April.

Adult Description. Male (Figs 2, 3, 6, 7, 9, 10). *Head*. Mid brown tending partly green on some individuals, live specimens always partly green; posterior margin of head partly or entirely edged black; ocellar triangle black, with continuous or partly broken band extending laterally to the margin of each eye; dorsal side of postclypeus and supra-antennal plates black; sometimes a black mark below antennal cavity. Ventral side of postclypeus glossy; yellowish brown, with black to varying degrees on transverse grooves (particularly towards anterior). Anteclypeus glossy; yellowish brown, usually with darker brown along midline. Rostrum yellowish brown to brown becoming black apically; reaching just



Figs 2–8. *Psaltoda fumipennis*: (2) male, Mt Lewis foothills, dorsal; (3) male, locality as previous, ventral; (4) female, Davies Creek camp node 7/8, dorsal; (5) female, locality as previous, ventral; (6) male neotype; (7) male, live adult, Davies Creek camp node 7/8; (8) female, live adult, locality as previous. Scale bars = 10 mm.

beyond bases of hind coxae. Eyes of live specimens bluish green. Antennae black.

Thorax. Pronotum mid brown tending green on some individuals, pronotal collar often partly green, particularly on live specimens, with lateral angles black; median and lateral fissures black; posterior transverse fissure black around dorsal midline and laterally below junction with lateral groove. Mesonotum similar in

colour to pronotum; midline with a thin black fascia broadest a little anterior of cruciform elevation; dorsolateral area with two black spots or wedge shaped patterns between submedian and lateral sigilla, broadest on anterior margin; anterior margin of cruciform elevation edged with black triangular markings; lateral sigilla incompletely marked, subtly darker than surrounds; submedian sigilla narrow, black; scutal depressions black; wing grooves with black on anterior margins. Underside of thorax mid brown, glossy, often substantially covered by silver pubescence.

Wings. Hyaline, with a smoky tint restricted to the distal, apical areas. Fore wing venation brown (tending bluish green in live specimens), 2A+3A black or partly so, R+Sc dark brown, some individuals with veins M, CuA and CuP+1A green or partly so; basal cell translucent yellow brown; crossveins forming bases of apical cells 2 and 3 (r and r-m) boldly infuscated mid brown to dark brown; weaker infuscations occur broadly along the apical half of veins RA_2 and RP; basal membrane grey. Hind wing venation usually brown; plaga on 3A cream surrounded by brown to dark brown, almost reaching distal end of 3A; vannal fold on 2A brown to dark brown, narrow, reaching full length; distal areas of cells a1–a3, part of a4 and adjacent wing margin boldly infuscated brown.

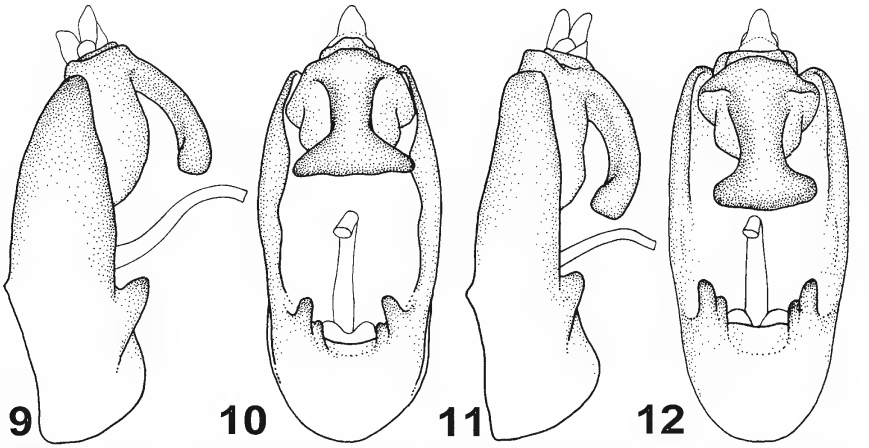
Legs. Glossy; dominantly yellowish brown or greenish. Fore legs with femoral primary spine short, rounded and not lying flat, secondary spine barely developed; browning at distal end of tibiae; tarsi brown; pretarsal claws dark brown and black. Mid legs similar to fore legs but slightly paler. Hind legs lacking black; pretarsal claws dark brown. Meracantha small, yellowish brown.

Opercula (Fig. 3). Broadly rounded, lateral margins almost straight, lateral angles and distal margins rounded, meeting or overlapping; distal margins not extending to the posterior margin of sternite 2; glossy; yellowish brown.

Abdomen. Tergites tending glossy; light brown, sometimes with a green flush in live specimens; tergites 1 and 2 with narrow black edgings at their junction in dorsal region; tergites 2 and 3 with narrow black edgings for the length of their junction; timbal covers slightly separated from opercula margin; mid brown. Sternites glossy; yellowish brown; anterior margin of sternite 3 narrowly edged black. Spiracles white.

Genitalia (Figs 9, 10). Pygofer basal lobe very small, lying tight against inner surface of upper lobe; upper lobe larger than basal lobe and clearly protruding beyond pygofer margin in lateral view; uncus in ventral view with a very wide distal expansion, sometimes approaching width of the inner margins of pygofer, tending broadly triangular, though variable in shape between individuals, the distal margin of the uncus straight or gently curved; in lateral view the uncus gently curved in a broad arc; aedeagus tubular, barely tapered, typical of *Psaltoda* species (cf. images in Moulds 2002).

Female (Figs 4, 5, 8). Similar to male. Abdominal segment 9 brown with a small black subdorsal marking on anterior half fused dorsally at anterior margin; dorsal



Figs 9–12. *Psaltoda* spp. male genitalia: (9, 10) *P. fumipennis*: (9) lateral view (from left side), Mt Lewis, gen. prep. PS70; (10) ventral view. (11, 12) *P. seismella* sp. n.: (11) lateral view (from left side), Mt Fisher, gen. prep. PS71; (12) ventral view.

beak dark brown. Ovipositor sheath black; terminating before apex of dorsal beak.

Measurements. Range and mean (in mm) for 10 males and 10 females. *Length of body*: ♂, 26.8–31.8 (29.1); ♀, 23.0–28.8 (24.7). *Length of fore wing*: ♂, 35.8–40.7 (38.5); ♀, 35.3–45.4 (38.5). *Width of fore wing*: ♂, 11.8–13.5 (12.8); ♀, 11.9–14.6 (12.7). *Width of head* (including eyes): ♂, 11.9–13.0 (12.5); ♀, 11.5–13.7 (12.3). *Width of pronotum* (across lateral angles): ♂, 11.0–12.1 (11.5); ♀, 10.6–12.7 (11.6). *Width of abdomen*: ♂, 10.4–12.1 (11.5); ♀, 9.6–12.0 (10.6).

Psaltoda seismella sp. n.

Zoobank registration: urn:lsid:zoobank.org:pub:F5855196-1E3C-4276-9F26-178DE7299D09

(Figs 1, 11–18)

Type material. Holotype ♂, label 1 (white card): 'Mt Fisher, 8 km SW / of Millaa Millaa, N. Qld / 21 Nov. 1979 / M. S. & B. J. Moulds'; label 2 (white card): 'QM Reg. No. / T250758'; label 3 (red card): 'HOLOTYPE / *Psaltoda seismella* / Popple & Moulds, 2021' (QM). *Paratypes.* QUEENSLAND: 1♂, 1♀, Boar Pocket, 13 mi. SWbyW of Gordonvale, 26.xii.1969, J.G. Brooks; 1♂, Mt Haig road, 10 km ENE. of Tinaroo Dam wall, Atherton Tableland, 17.07S 145.38E [corrected to 17°07′S 145°38′E], 3.ii.1988, D.C.F. Rentz, Stop A-14 (ANIC). 1♀, "Chowchilla", Topaz, 25.i.1988, [no collector], [ex. W.T. Cooper collection], T235309; 1♀, "Chowchilla", Topaz, 4.iii.1991, W.T. C[ooper], [ex. W.T. Cooper collection], T235311; 1♂, "Chowchilla", Topaz, i.2006, [no collector], [ex. W.T. Cooper collection], T235307; 1♂, 1♀, 17°15′Sx145°51′E, Bellenden Ker, top stn., 30.xi–2.xii.1998, hand, G. Monteith, P. Bouchard & D. Cook, 1500 m, [sample code] 1991, T235303 & T235304; 1♂, 2♀♀, Paluma Dam, 30–31.xii.1964, G. Monteith, T235306, T235310, T235312 (QM). 1♂, Herberton Range, 17°17′28″S 145°25′26″E, 19.xii.2006, L. Popple, A.M. & A.E. McKinnon, 100-0001; 1♂, Nerada Tea Factory, 17°23′05″S

145°40′01″E, 3.i.2019, L.W. Popple, A.E. McKinnon, recorded, 100-0002 (LWP). 20♂♂ (1 genitalia prep. PS55), 9♀♀ (1 Simon Lab. voucher 05.AU.QL.JOP.12), Merragallan Rd, nr Malanda, 17°25.118′S 145°32.530′E, 852 m, 15.ii.2010, Hill Marshall, Moulds, Olive; 2♂♂ (1 genitalia prep. PS71), 3♀♀, Mt Fisher, 8 km SW. of Millaa Millaa, 21.xi.1979, M.S. & B.J. Moulds; 1♂, Bartle Frere, 27.xii.2000, A. Polac; 1♀, Zillie Falls, nr Millaa Millaa, 22.ii.1982, M.S. & B.J. Moulds; 1♂, 'Chowchilla', Topaz CTL, 25.xi.2000, W.T. C[ooper]; 2♂♂, 2♀♀, S. of Ravenshoe, 30.xi.1987, J. Booy; 2♂♂, 1♀, Wondecla, near Herberton, 4–8.i.1981, G. Wood; 1♂, Paluma, 6.i.1986, E.E. & E.W. Adams; 1♂, Paluma, 11.xii.1980, M.S. & B.J. Moulds; 1♀, Paluma, 900 m, 17.xii.1988, H. & A. Howden; 1♀, Mt Spec, Paluma Ra., 5–7.i.1965, J.G. Brooks; 1♀, Bluewater State Forest, S. end Paluma Rg., WNW. of Townsville, 31.i.1981, M.S. & B.J. Moulds (MSM).

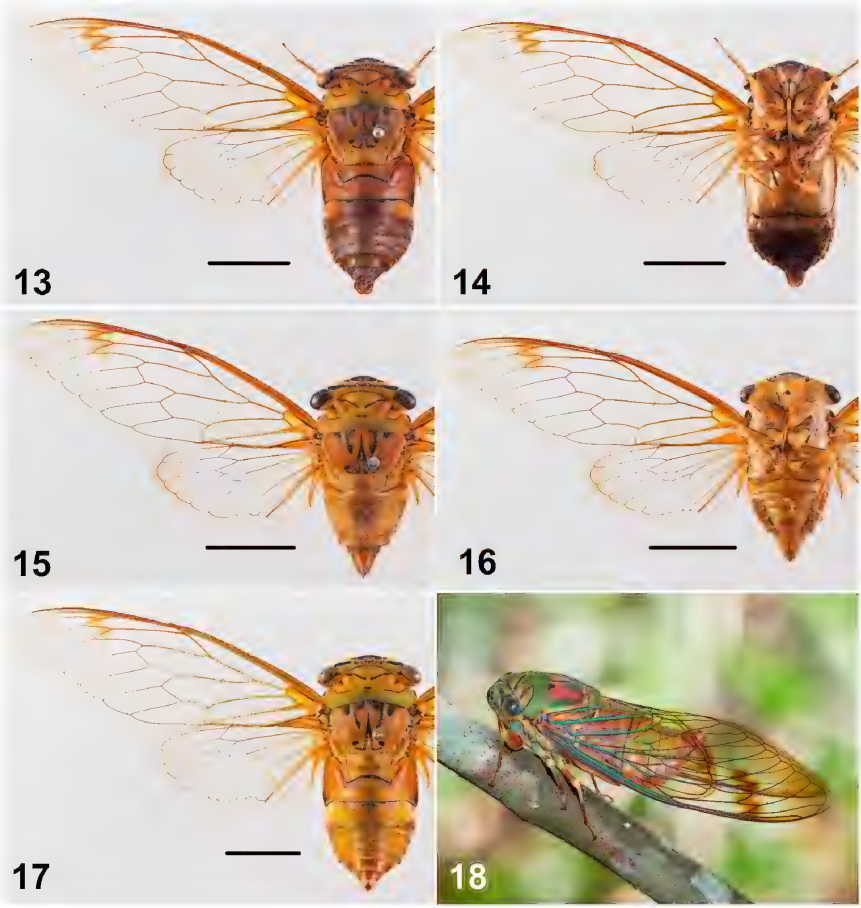
Audio recording localities. QUEENSLAND: Mt Edith Road, 17°04′49″S 145°36′24″E, 3.i.2021; Kauri Creek Road, 17°05′36″S 145°35′12″E, 29.ii.2020; Lake Barrine, 17°14′43″S 145°38′21″E, 1.i.2008; Boar Pocket Road, 17°12′15″S 145°39′59″E, 29.ii.2020; Malanda, 17°21′20″S 145°35′11″E, 3.i.2019; Gadgarra National Park, 17°16′23″S 145°39′58″, 21.iii.2020; Nerada Tea Factory, 17°23′05″S 145°40′01″E, 3.i.2019; Herberton Range, 17°17′28″S 145°25′26″E, 19.Dec.2006; McClelland Lookout, Paluma, 19°00′28″S 146°12′45″E, 1.xii.2018 (LWP). McHugh Lookout, 17°31′13″S 145°34′04″E, 30.i.2003; Tully Falls Weir, 17°46′38″S 145°33′53″E, 30.i.2003 (AE).

Distribution, habitat and seasonality (Fig. 1). This species occurs from Mt Edith and Mt Haig north of Tinaroo Dam south to Tully Falls Weir near Ravenshoe, with an additional occurrence further south from Mt Spec in the Paluma Range south to Bluewater State Forest (now included in Paluma Range National Park). The gap in distribution between the Tully Falls area and Paluma Range is likely an artefact of limited sampling in the area. Populations occur in rainforest, including areas with residual trees in partially cleared landscapes adjacent to remnant rainforest patches, at elevations >680 m. Adults occur from late November to March.

Etymology. Derived from the Greek word for earthquake, *seismella* (a noun in apposition) which translates to "little earthquake". The name reflects the shaking quality of the song, which is characteristic of the species.

Adult Description. Male (Figs 11–14, 17, 18). *Head*. Mid brown tending partly green on some individuals, live specimens always partly green; posterior margin of head partly or entirely edged black; ocellar triangle black, with continuous or partly broken band extending laterally to the margin of each eye; dorsal side of postclypeus and supra-antennal plates black; sometimes a black mark below antennal cavity. Ventral side of postclypeus glossy; yellowish brown, with black to varying degrees on transverse grooves (particularly towards anterior). Anteclypeus glossy; yellowish brown, usually with darker brown along midline. Rostrum yellowish brown to brown becoming black apically; reaching just beyond bases of hind coxae. Eyes of live specimens bluish green. Antennae filiform, black.

Thorax. Pronotum mid brown tending green on some individuals, pronotal collar often partly green, particularly on live specimens, with lateral angles black; median and lateral fissures black; posterior transverse fissure black around dorsal



Figs 13–18. *Psaltoda seismella* sp. n.: (13) male holotype, dorsal; (14) male holotype, ventral; (15) female, Zillee Falls nr Millaa Millaa, dorsal; (16) female, locality as previous, ventral; (17) male, Herberton Range, dorsal; (18) male, live adult, Nerada Tea Factory. Scale bars = 10 mm.

midline and laterally below junction with lateral groove. Mesonotum similar in colour to pronotum; midline with a thin black fascia broadest a little anterior of cruciform elevation; dorsolateral area with two black spots or wedge shaped patterns between submedian and lateral sigilla, broadest on anterior margin; anterior margin of cruciform elevation edged with black triangular markings; lateral sigilla ill-defined; submedian sigilla narrow, black, sometimes broadening anteriorly and meeting at the anterior margin; scutal depressions black; wing grooves with black on anterior margins. Underside of thorax mid brown, glossy, often substantially covered by silver pubescence.

Wings. Hyaline, with a smoky tint restricted to the distal, apical areas. Fore wing venation brown tending bluish green in some specimens, 2A+3A black or partly so, R+Sc M, CuA and CuP+1A often green or partly so; basal cell translucent orange; crossveins forming bases of apical cells 2 and 3 (r and r-m) boldly infuscated brown to dark brown; apical cells with a smoky tint; basal membrane orange. Hind wing venation usually brown; plaga on 3A orange surrounded by orange brown, almost reaching distal end of 3A; ventral fold on 2A orange brown to brown, narrow, reaching full length; distal areas of cells a1–a3 and adjacent wing margin with a weak brown infuscation centred on the ambient vein.

Legs. Glossy; dominantly yellowish brown or greenish. Fore legs with femoral primary spine short, rounded and not lying flat, secondary spine barely developed; browning at distal end of tibiae; tarsi brown; pretarsal claws dark brown and black. Mid legs similar to fore legs but slightly paler. Hind legs lacking black; pretarsal claws dark brown. Meracantha small, yellowish brown.

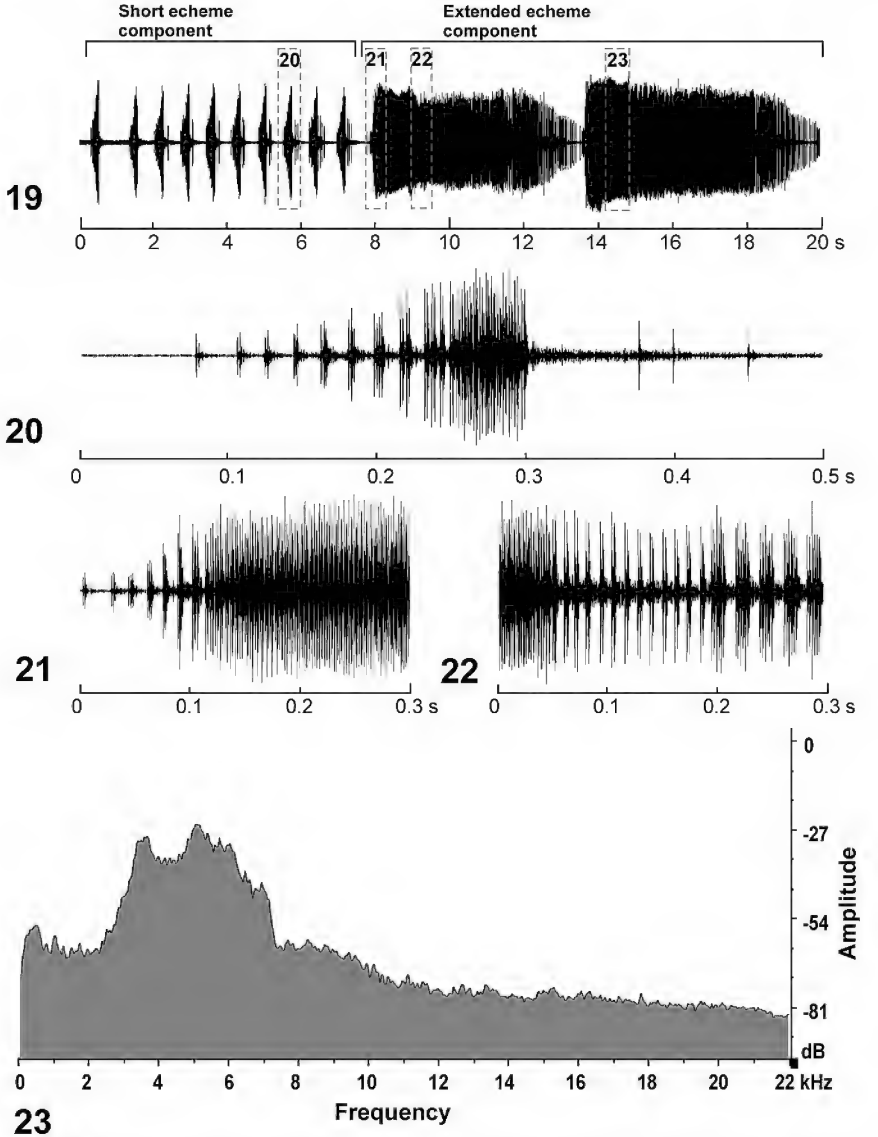
Opercula (Fig. 14). Broadly rounded to somewhat triangular, lateral and distal margins almost straight, meeting or overlapping; lateral angles sometimes rounded; distal margins extending to or almost extending to the posterior margin of sternite 2; glossy; yellowish brown.

Abdomen. Tergites tending glossy; light brown, sometimes with a green flush in live specimens; tergites 1 and 2 with narrow black edgings at their junction in dorsal region; tergites 2 and 3 with narrow black edgings for the length of their junction; timbal covers slightly separated from opercula margin; mid brown. Sternites glossy; yellowish brown; anterior margin of sternite 3 narrowly edged black. Spiracles white.

Genitalia (Figs 11, 12). Pygofer basal lobe very small, lying tight against inner surface of upper lobe; upper lobe larger than basal lobe and clearly protruding beyond pygofer margin in lateral view; uncus with a very wide distal expansion, variable in shape between individuals, sometimes tending slender with rounded extremities, sometimes tending broadly triangular with less rounded extremities, the distal margin of the uncus straight or gently curved; in lateral view the uncus gently curved in a broad arc; aedeagus tubular, barely tapered, typical of *Psaltoda* species (cf. images in Moulds 2002).

Female (Figs 15, 16). Similar to male. Abdominal segment 9 brown with a small black subdorsal marking on anterior half fused dorsally at anterior margin; dorsal beak dark brown. Ovipositor sheath black; terminating before apex of dorsal beak.

Measurements. Range and mean (in mm) for 10 males and 10 females. *Length of body*: ♂, 26.5–32.7 (30.5); ♀, 23.3–25.1 (24.5). *Length of fore wing*: ♂, 37.1–43.9 (41.2); ♀, 36.8–41.2 (39.1). *Width of fore wing*: ♂, 11.6–14.3 (13.2); ♀, 11.9–13.1 (12.6). *Width of head* (including eyes): ♂, 11.7–13.5 (12.9); ♀, 11.4–13.1 (12.4). *Width of pronotum* (across lateral angles): ♂, 10.6–12.8 (11.8); ♀, 10.4–12.6 (11.5). *Width of abdomen*: ♂, 10.3–12.9 (11.9); ♀, 9.4–11.5 (10.4).



Figs 19–23. Calling song of *Psaltoda fumipennis*, illustrated from a recording taken by LWP at Mt Lewis foothills: (19) Wave plot illustrating the short echeme and extended echeme components; (20) wave plot showing expanded detail of a single short echeme, including initial short syllables, long syllable and three discrete pulses; (21) wave plot showing expanded detail of beginning of extended echeme; (22) wave plot showing expanded detail of progression of extended echeme with decay of syllable coalescence; (23) frequency spectrogram.

Morphological distinguishing features

Both *P. fumipennis* and *P. seismella* key out to *P. fumipennis* in Moulds (2002). The following combination of characters can be used to distinguish both of these species from other *Psaltoda* species:

- hind wings with some degree of infuscation or tint apically,
- head not black posterior to ocelli, and
- fore wing infuscation not overlaying longitudinal veins at their junction with ambient vein.

In most cases, the species of *Psaltoda* exhibit distinguishing features in the male genitalia. However, the male genitalia of *P. seismella* are almost indistinguishable from those of *P. fumipennis*. The shape of the distal expansion of the uncus is similar in both species and variable between individuals but usually the length of each lateral lobe of the distal expansion is shorter than the narrowest portion of the uncal shaft in *P. seismella*, whereas in *P. fumipennis* these are longer or of similar length to the narrowest portion of the uncal shaft.

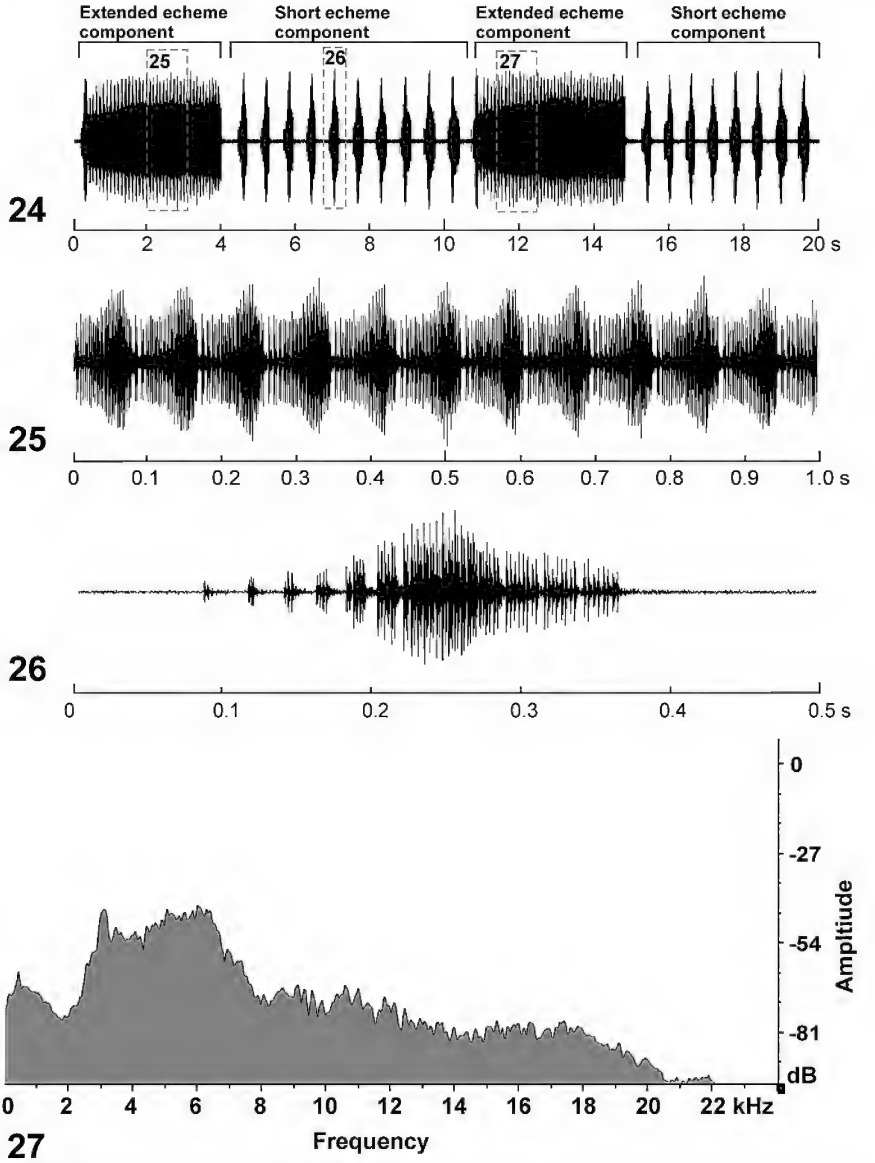
The following wing features are reliable for distinguishing *P. seismella* from *P. fumipennis*:

- basal cell, basal membrane and plaga are orange (cf. brown, grey and cream, respectively in *P. fumipennis*), and
- in mature specimens, the distal areas of the hind wing apical cells are weakly tinted, to a similar extent to the distal areas of the fore wing apical cells (cf. boldly tinted, to the same extent as the fore wing infuscation surrounding veins r and r-m in *P. fumipennis*).

Calling songs

Diagrams showing a breakdown of the calling songs of *P. fumipennis* and *P. seismella* are provided in Figs 19–23 and Figs 24–27, respectively. While there are clear similarities between the calling songs of these species, both the repetition patterns and the more detailed structures display obvious differences. Each species produces two different calling song components: a repeated, short echeme and an extended echeme (Figs 19 and 24). The short echeme is repeated at a similar rate in both species (approximately 1.0–1.8 per second); however, there are clear differences in temporal structure (refer to Figs 28–37 for comparisons). In *P. fumipennis*, each short echeme (illustrated in Fig. 20 and Figs 28–32) commences with 8–12 short syllables, each successively increasing in amplitude, and each separated by successfully decreasing gaps (total duration 180–340 ms). The short syllables are followed by a higher amplitude longer syllable (60–80 ms), a silent gap (60–180 ms, typically 70–90 ms), then 1–3 soft individual pulses (e.g. Figs 20, 29). In more distant recordings the soft pulses may remain undetected (e.g. Fig. 28) and, in less clear recordings, they may be partly or completely obscured by background sounds (e.g. Figs 30–32).

In *P. seismella*, each short echeme (illustrated in Fig. 26 and Figs 33–37) commences with 5–7 short syllables, each successively increasing in amplitude,



Figs 24–27. Calling song of *Psaltoda seismella* sp. n., illustrated from a recording taken by LWP at Nerada Tea Factory: (24) Wave plot illustrating the short echeme and extended echeme components; (25) wave plot showing expanded detail of beginning of extended echeme; (26) wave plot showing expanded detail of a single short echeme, including short syllables followed by a long, high amplitude, syllable and three quieter syllables; (27) frequency spectrogram.

and each separated by successively decreasing gaps (total duration 130–190 ms). These are followed by a longer syllable (50–70 ms duration), then 2–4 closely-spaced and slightly quieter syllables with successively decreasing amplitude (70–100 ms duration). Rarely, these may be followed by 1–2 soft pulses.

In *P. fumipennis*, the long gap immediately following the longest highest amplitude syllable in each short echeme of *P. fumipennis*, along with the intervening soft pulses heard at close quarters, gives this component an abrupt, crackling quality. By contrast, in *P. seismella*, the presence of lower amplitude syllables prior to and following the long syllable gives its short echeme component, a rolling, more rounded quality. These differences can be useful for distinguishing the calls when both species are producing this call component at the same location (e.g. Figs 32, 37).

In *P. fumipennis*, the extended echeme component consists of a series of long echemes. Each long echeme is a loud roar, which tails off gradually with a variable warbling quality (Fig. 19; total duration typically 5–7 s). Close examination of the initial 1–2 s of each echeme reveals a sequence of coalesced syllables (Fig. 21). The next 1–2 s exhibit a progressive, sometimes uneven, decay of coalescence coinciding with a reduction in amplitude (Fig. 22). The final 40–50% of the echeme shows stablised and evenly spaced syllables and a continued gradual reduction in amplitude (Fig. 19). The extended echemes of *P. fumipennis* are often repeated several times in succession (e.g. Figs 38–43), a characteristic not exhibited by *P. seismella*.

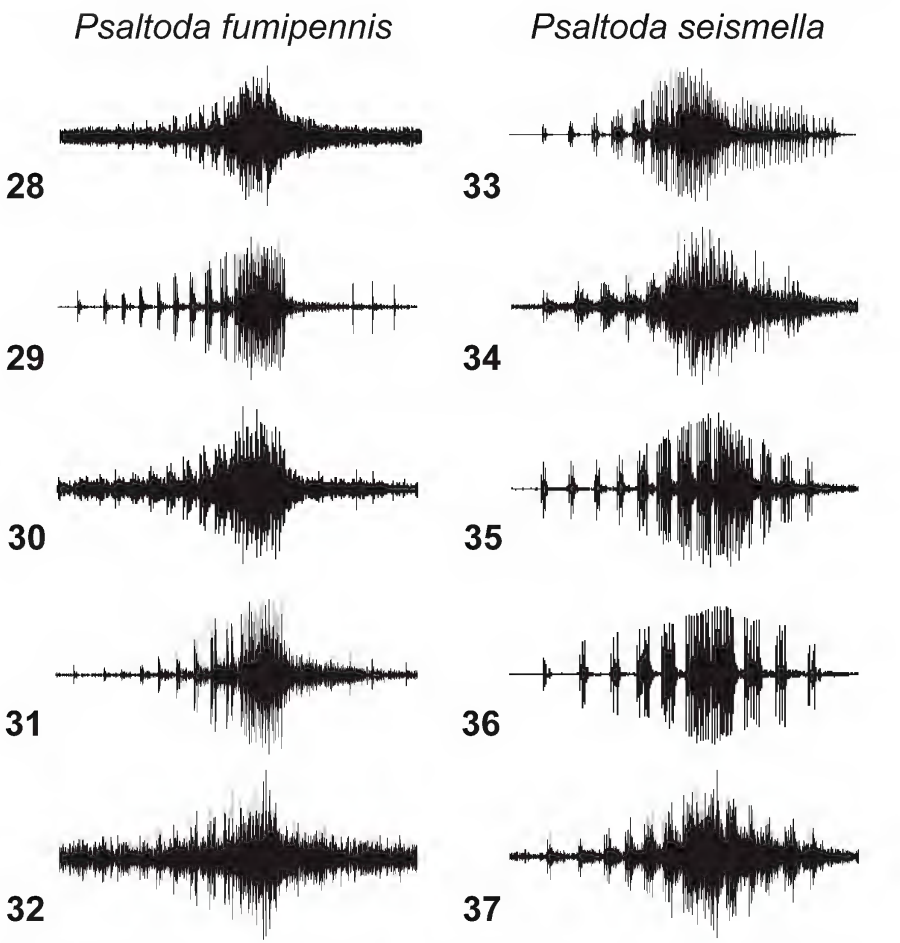
The extended echeme component of *P. seismella* comprises a single long echeme, which is produced between each bouts of the short echeme component (Fig. 24). Each long echeme has a definitive "shaking" quality (total duration 6–8 s). Close inspection reveals that the shaking results from a series of closely spaced, long syllables (each *ca* 100 ms; Fig. 25). Each syllable exhibits a weak amplitude increase towards the end (Fig. 25). Unlike *P. fumipennis*, the echeme does not exhibit a change in temporal structure as it progresses (cf. Fig. 22).

Both species share similar frequency spectra, with highest amplitudes distributed between 3.0 and 7.0 kHz (Figs 23, 27). For each species, the broader temporal calling song pattern is consistent across their geographical distributions, as shown for *P. fumipennis* in Figs 38–43 and for *P. seismella* in Figs 44–50.

Discussion

Distribution, habitat preferences and overlap zone

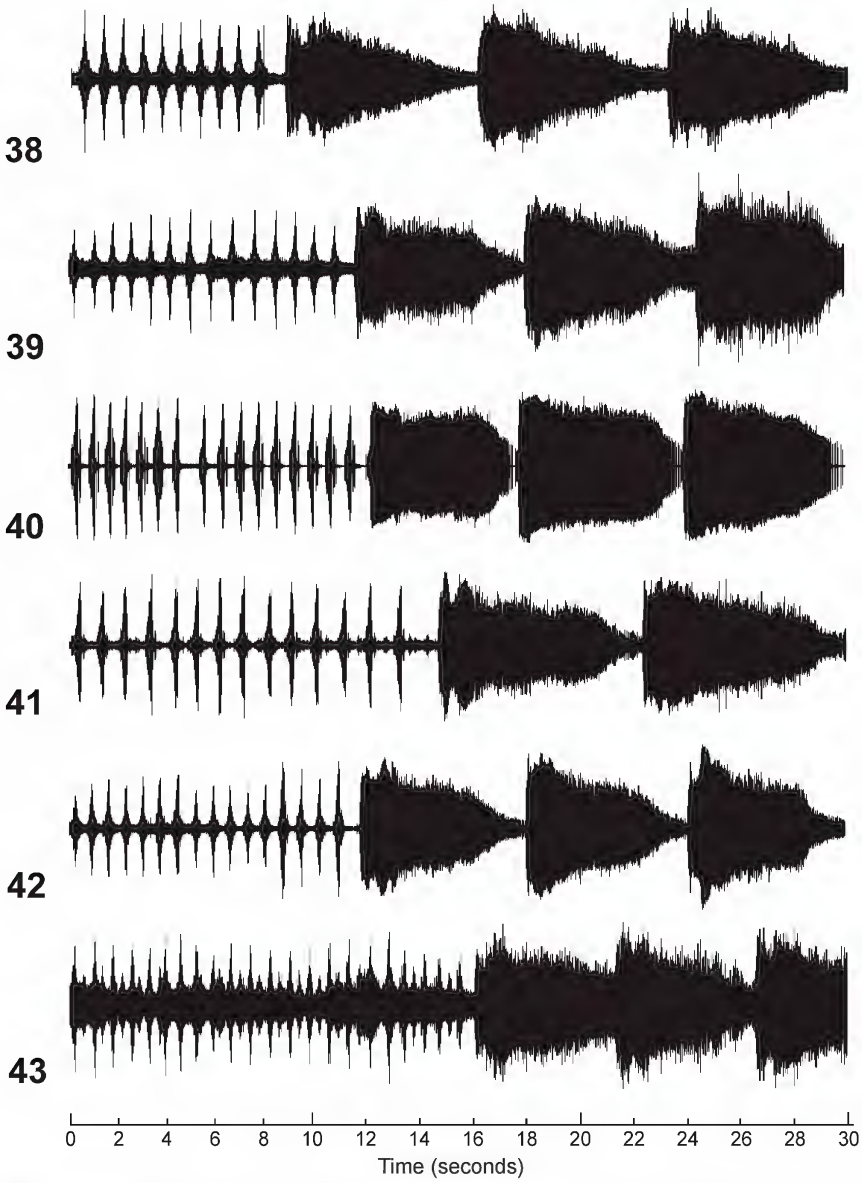
Together, *P. fumipennis* and *P. seismella* have a distribution that spans the Wet Tropics bioregion in northern Queensland from near Cooktown south to Paluma Range National Park. Within this distribution, *P. seismella* is restricted to areas of pure rainforest >680 m altitude. It persists in isolated fragments that are scattered across the Atherton Tableland, which has been extensively cleared for agriculture. In contrast, *P. fumipennis* occurs across a broader elevation profile with broader habitat tolerances, ranging from pure rainforest to rainforest margins and



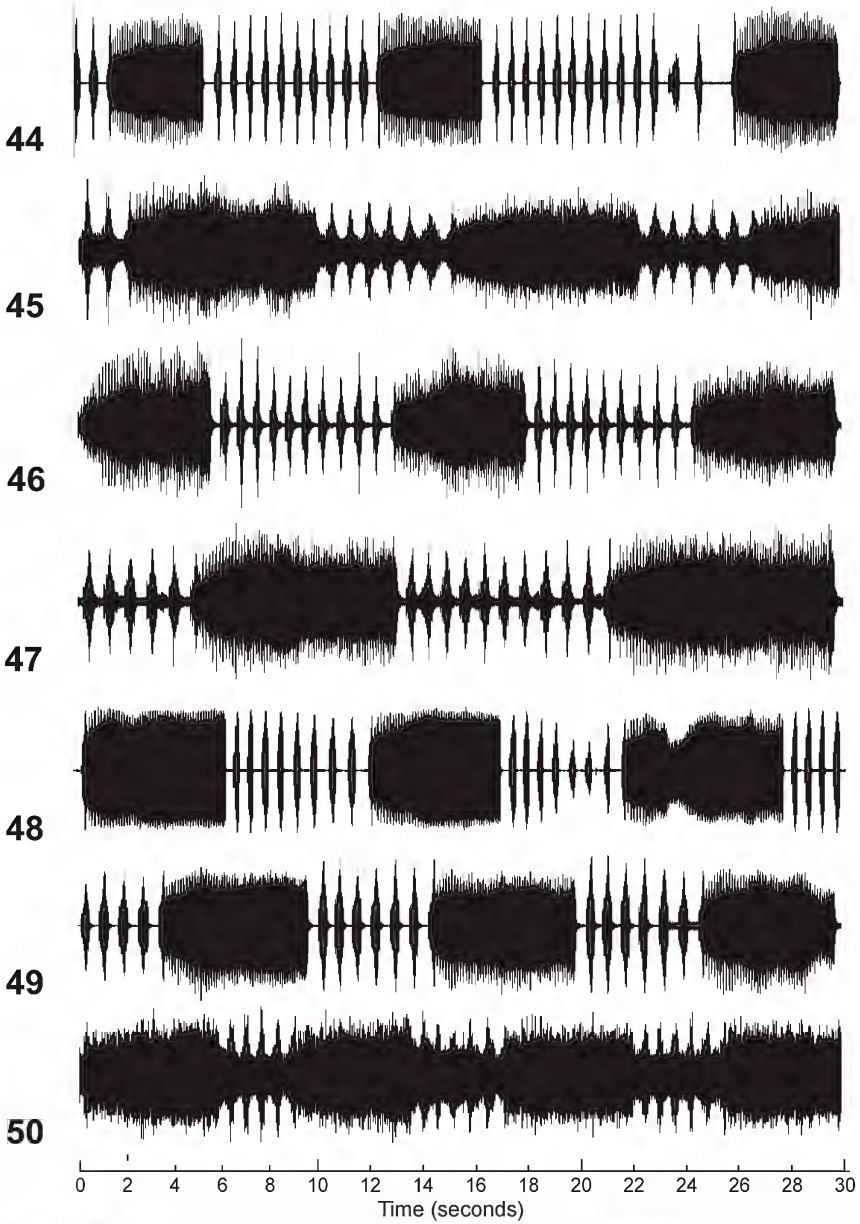
Figs 28–37. Wave plots comparing the temporal structure of a single short echeme from the short echeme component of the calling song of *Psaltoda fumipennis* and *Psaltoda seismella* sp. n. cicadas from multiple localities. *Psaltoda fumipennis*: (28) Black Mountain Road; (29) Mt Lewis foothills; (30) Davies Creek camp node 7/8; (31) Lake Morris Road; (32) Boar Pocket Road. *Psaltoda seismella* sp. n.: (33) Nerada Tea Factory; (34) Herberton Range; (35) McHugh Lookout; (36) Tully Gorge Weir; (37) Boar Pocket Road. All recordings by LWP, except (35) and (36), which were recorded by A. Ewart.

ecotones, including areas where rainforest is a successional component of wet sclerophyll forest. The host plant associations of the two species are unknown.

There is a small area of overlap in distribution, where both species occur together (in sympatry) in the middle of the Wet Tropics on the upper section of the Gillies Range road (between approximately 700 and 800 m altitude), which intersects rainforest. This section of road is 5.5 km long (approximately 3 km linear



Figs 38–43. Calling song of *Psaltoda fumipennis* illustrated in wave plots from different localities: (38) start of Surprise Creek track, Barron Gorge NP; (39) Black Mountain Road, Kuranda; (40) Mt Lewis foothills; (41) Davies Creek camp node 7/8; (42) Lake Morris Road; (43) Boar Pocket Road. All recordings by LWP.



Figs 44–50. Calling song of *Psaltoda seismella* sp. n. illustrated in wave plots from different localities: (44) Nerada Tea Factory; (45) Mount Edith Road; (46) Herberton Range; (47) Boar Pocket Road; (48) McHugh Lookout; (49) Tully Gorge Weir; (50) McClelland Lookout, Paluma. All recordings by LWP, except (48) and (49), which were recorded by A. Ewart.

distance). Nearby, at Boar Pocket Road (Danbulla), both species occur together in isolated patches of mature regrowth. Further south, specimens of both species have been collected from the summit of Mt Bellenden Ker at approximately 1580 m altitude (the southern limit of *P. fumipennis*). North of the overlap zone, the two species appear to be separated in the vicinity of the Lamb Range, with *P. fumipennis* occurring in the upper Davies Creek area (Dinden National Park) and *P. seismella* occurring at its northern limit in the Mt Haig–Mt Edith area (Danbulla National Park) adjacent to the Lamb Range.

Biogeography

The most widely documented biogeographical barrier in the Wet Tropics, is the Black Mountain Corridor (Taberlet 1998; Chapple *et al.* 2011; Bryant & Krosch 2016). This barrier is approximately 60 km wide and is a demonstrated suture zone for flora (although not definitive; Edwards *et al.* 2017) and, particularly, fauna. It is associated with vicariant distributions in rainforest plants and animals due to repeated contractions of rainforest during quaternary climatic oscillations, peaking at the Last Glacial Maximum (Taberlet 1998; Bryant & Krosch 2016). The distributions of the two *Psaltoda* species relative to this barrier is shown in Fig. 1. *Psaltoda seismella* reaches its northern limit in the vicinity of the Lamb Range and does not extend into the Black Mountain Corridor. In contrast, the distribution of *P. fumipennis* passes through the Black Mountain Corridor. The difference in distribution between the two species in relation to the Black Mountain Corridor may relate to differences in elevation and/or habitat association. The Black Mountain Corridor presents a wide gap between areas of higher elevation, that today retains pockets of rainforest interspersed among drier habitats. This may explain why *P. fumipennis,* with its broader elevation and habitat tolerances, has been able to pass through and occupy this barrier when *P. seismella* has not. The area of overlap between the two species is notable for being located south of the Black Mountain Corridor. Studies of several other invertebrate groups have revealed similar distributional patterns that are also anomalous with respect to the Black Mountain Corridor and which have contact zones in the vicinity of the Lamb Range and/or Atherton Tableland (e.g. Bell *et al.* 2004, 2007; Moreau *et al.* 2015; Reid 2000; Reid & Storey 2000).

Edwards *et al.* (2017) documents two other biogeographical barriers within the Wet Tropics bioregion (the Atherton Tableland barrier and the Townsville Lowlands-Paluma Range barrier); however, these barriers are only likely to influence the distribution of species that are associated with habitats other than upland rainforest, so they are not considered relevant here.

The reason for the distribution of *P. fumipennis* not extending south beyond Mt Bellenden Ker is unclear. It may be an artefact of collecting, although we consider that unlikely considering the number of locality records, but the possibility cannot be dismissed. If we accept Mt Bellenden Ker as the present day southern limit of *P. fumipennis* then among the possible reasons for this could be that *P. fumipennis* has reached its southern limit of climate tolerance

and/or that of its host plant(s). Alternatively, competitive interactions may occur between *P. fumipennis* and *P. seismella*, thereby limiting the southern expansion of *P. fumipennis* through the distribution of *P. seismella*. The exploration of these and other possibilities would require further study. An investigation into the population genetics and phylogeography of these species may provide further insights into their biogeography.

Acknowledgements

For the genitalia drawings we thank Ivan Nozaic. Permits for LWP specimens were collected under the authorisation of permits held by the Entomological Society of Queensland (administered by Chris Lambkin, Queensland Museum). Susan Wright provided reference photographs and database information for QM material. David Marshall provided helpful discussions about species limits and anomalous contact zones. Geoff Monteith offered helpful comments and suggested references, which improved the biogeography discussion. Tony Ewart provided access to his library of recordings. Fig. 1 was compiled with SimpleMappr.

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NOTES ON THE SPECIES OF *MOLOPHILUS* (*SUPERBOMOLOPHILUS*) THEISCHINGER, 1988 (DIPTERA: LIMONIIDAE), WITH A DESCRIPTION OF A NEW SPECIES

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Abstract

An overview of *Molophilus* (*Superbomolophilus*) Theischinger, an Australian endemic subgenus is given. One new species is described: *Molophilus* (*Superbomolophilus*) *rowanorum* **sp. n.** from the Glen Valley region of Victoria, Australia. An identification key is provided to the males of the now 11 species.

Keywords: taxonomy, review, illustrations, key, new species

Introduction

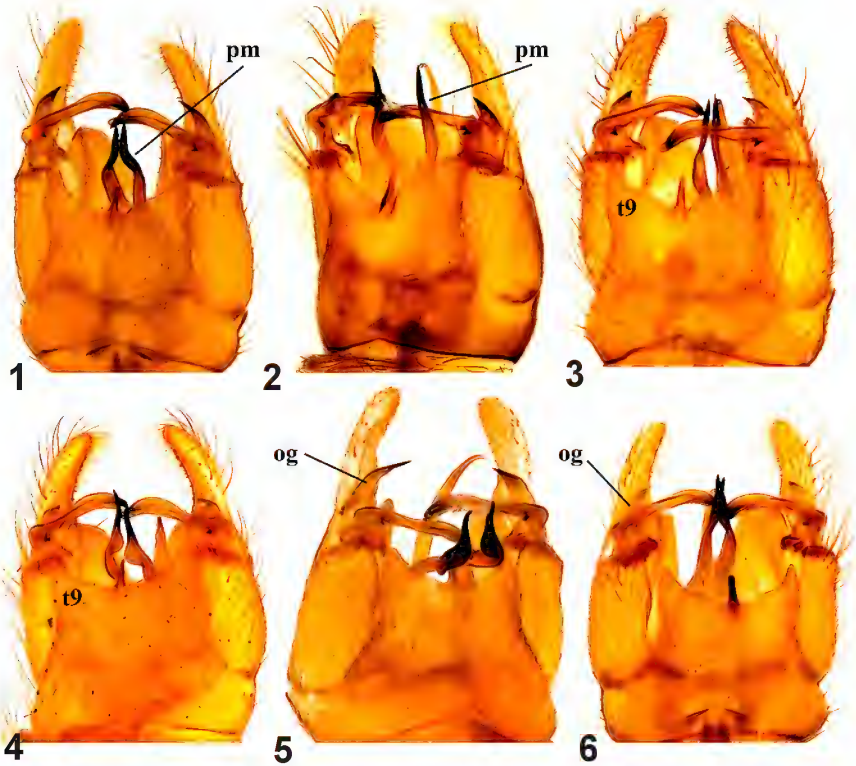
The crane fly genus *Molophilus* Curtis, 1833 shows remarkable diversity in Australia, with many species and several endemic subgenera. Included among these endemic taxa is the subgenus *Superbomolophilus* Theischinger, 1988, with ten species according to Oosterbroek (2021), raised to eleven including the species newly described here.

Species of s.g. *Superbomolophilus* are distributed along the eastern coast of Australia from Queensland to Tasmania with one species known also from central Australia. These crane flies are distinguished from those of other subgenera of *Molophilus* by having the parameres completely separate, each connected to the base of the mesal face of the gonocoxites. The key provided by Theischinger (1996b) aids greatly in distinguishing the subgenera of *Molophilus.*

The present paper provides an overview of the variation within and between species and discusses some of the morphological traits that allow inference of interspecies relationships across the subgenus. It also further adds to the limoniid biodiversity of the Australian fauna by describing a newly discovered species from Victoria.

Materials and methods

Specimens were collected by sweeping a hand net through vegetation and then preserved in 100% ethanol. As a result of this preservation, the colour of specimens might have changed from the natural state. The male terminalia (hypopygium) of specimens were examined by clearing in KOH then displayed and preserved in a 40% glycerol to ethanol solution. Line illustrations of the hypopygia were made using a camera lucida attachment on a stereo microscope. The photographic images of *Molophilus* (*Superbomolophilus*) *rowanorum* **sp. n.**



Figs 1–6. *Molophilus* (*Superbomolophilus*) *froggatti*, hypopygia, ventral view: (1) Gembrook, Victoria; (2) Tom Groggin, Victoria; (3) Grampians, Victoria; (4) Black Mountain, New South Wales; (5) Beerwah, Queensland; (6) Omeo, Victoria

were taken on a Zeiss Stemi 2000-C stereo microscope using a Tucsen TCA-CMOS camera, then edited using Adobe Photoshop CS2 image software.

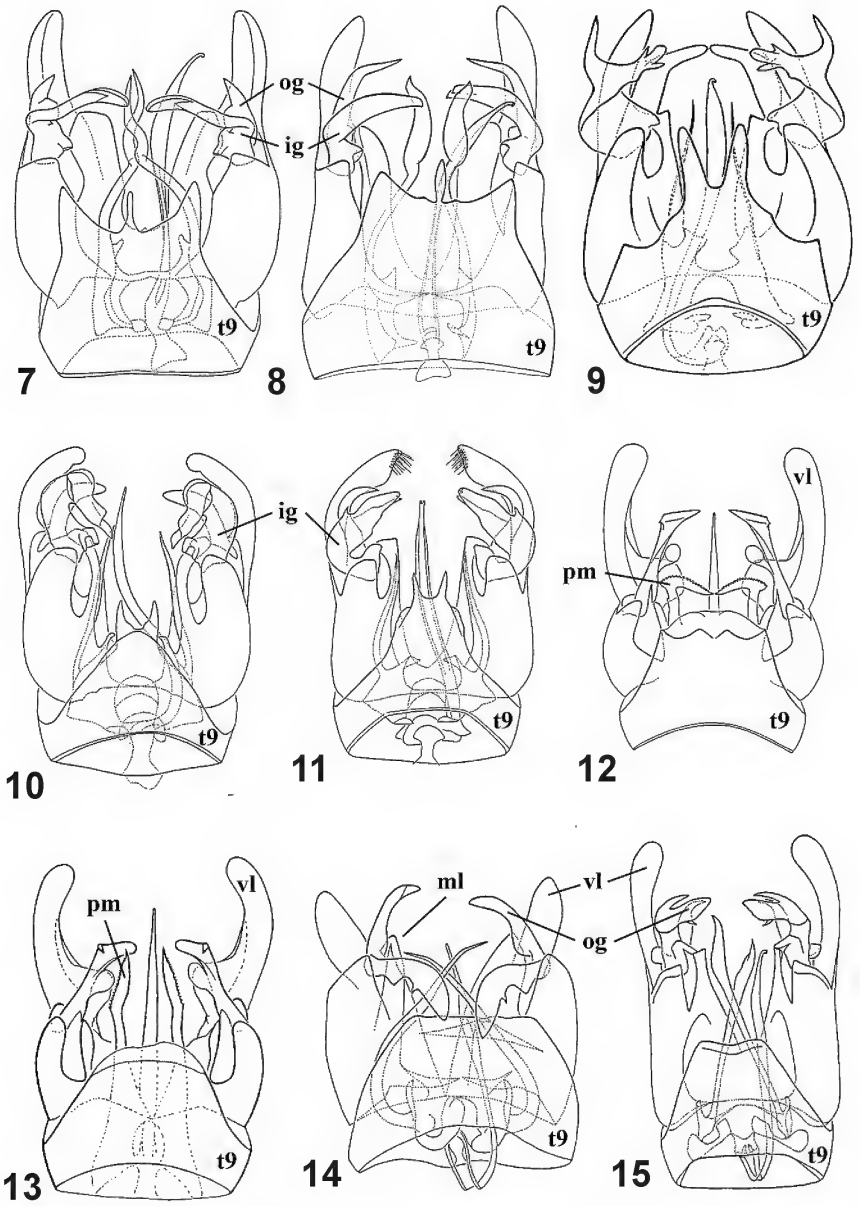
Specimens have been deposited in the Museum Victoria (NMV) collection, and in a vouchered research collection at the GHD Water Sciences laboratory in Melbourne.

Descriptive terminology is in accord with McAlpine (1981).

Abbreviations as used in figures: *ae*, aedeagus; *ig*, inner gonostylus; *ml*, medial lobe of gonocoxite; *og*, outer gonostylus; *pm*, parameres; *t9*, tergite 9; *vl*, ventral lobe of gonocoxite.

Notes on *Superbomolophilus*

Like most *Molophilus*, the species of *Superbomolophilus* are superficially quite similar, with specific differences in the structures of the male genitalia. The



Figs 7–15. *Molophilus* (*Superbomolophilus*) hypopygia, ventral view (modified from Theischinger 1988, 1992, 1994, 1996a and Billingham & Theischinger 2019): (7) *M.* (*S.*) *froggatti*; (8) *M.* (*S.*) *barringtonensis*; (9) *M.* (*S.*) *osterhas*; (10) *M.* (*S.*) *brumby*; (11) *M.* (*S.*) *cooloola*; (12) *M.* (*S.*) *kunara*; (13) *M.* (*S.*) *undia*; (14) *M.* (*S.*) *gigas*; (15) *M.* (*S.*) *marriwirra*.

species show great variation in the shape and armature of the 9th tergite, the shape of the ventral and mesal lobes of the gonocoxite, size and shape of the gonostyli, and the form of the parameres. The males are readily separated using the key provided below.

This marked variation in the male genitalia makes interpretation of affinities across the subgenus difficult, however some similarities are apparent; *M.* (*S.*) *osterhas* Theischinger, 1994, *M.* (*S.*) *brumby* Theischinger, 1988, and *M.* (*S.*) *cooloola* Theischinger, 1992, appear to form a natural grouping with all bearing a pair of distinct lobes or projections on the posterior margin of tergite 9. *Molophilus* (*S.*) *kunara* Theischinger, 1992, and *M.* (*S.*) *undia* Theischinger, 1996a, closely resemble each other, each having a prominent baso-medial expansion on the ventral lobe of the gonocoxite. *Molophilus* (*S.*) *froggatti* Skuse, 1890 and *M. (S.) barringtonensis* Billingham & Theischinger, 2019, appear to be sister species, sharing the 9th tergite with three distinct lobes or projections, as well as having quite similar inner gonostyli and parameres. Whereas *M.* (*S.*) *inelegans* Alexander, 1927, is quite similar to *M.* (*S.*) *marriwirra*, Theischinger, 1992, *M.* (*S.*) *gigas* Alexander, 1922, with gonostyli reaching beyond tip of ventral lobe of gonocoxite, appears somewhat isolated.

Molophilus (*Superbomolophilus*) *froggatti* is perhaps the most widespread and commonly encountered species of s.g. *Superbomolophilus*, occurring from southern Queensland, across eastern New South Wales, throughout Victoria and into Tasmania. The species appears to be somewhat variable and specimens have been found with notable differences in the male genitalia. These include; parameres varying from distally greatly sinuous to nearly straight (Fig. 1 vs Fig. 2), dorsal lobe of tergite 9 deeply concave and v-shaped to broadly concave and u-shaped (Fig. 3 vs Fig. 4), and outer gonostylus from 1/2 to 1/4 the length of the inner gonostylus (Fig. 5 vs Fig. 6). Interestingly however these variations do not seem to follow any geographic patterns, as might be expected for such a wide ranging species, and, given the evidence available, the different variants are not considered to represent distinct species or subspecies.

Key to the males of *Molophilus* (*Superbomolophilus*)

1 Tergite 9 with distinct posterior lobes or processes (Figs 7–11) 2
Tergite 9 without distinct posterior lobes or processes (Figs 12–15) 6

2 Tergite 9 with 3 posterior lobes or processes (Figs 7, 8) 3
Tergite 9 with a pair of posterior lobes or processes (Figs 9–11) 4

3 Inner gonostylus markedly longer than outer gonostylus (Fig. 7) ..... *froggatti*
Inner and outer gonostylus subequal in length (Fig. 8) ..... *barringtonensis*

4 Posterior processes of tergite 9 long and not acutely pointed (Fig. 9) ..... *osterhas*
Posterior processes of tergite 9 short and acutely pointed (Figs 10, 11) 5

5 Inner gonostylus strongly bent at midlength (Fig. 10) ..... *brumby*
Inner gonostylus not bent at midlength (Fig. 11) ..... *cooloola*

6 Ventral lobe of gonocoxite with baso-medial expansion (Figs 12, 13) 7
Ventral lobe of gonocoxite without baso-medial expansion (Figs 14, 15) 8

7 Parameres with perpendicular subapical bend (Fig. 12) ..... *kunara*
Parameres with only slight subapical bend (Fig. 13) ..... *undia*

8 Median lobe of gonocoxite prominent (Fig. 24) ..... *rowanorum* sp. n.
Median lobe of gonocoxite not prominent (Figs 14, 15) 9

9 Gonostyli reaching beyond tip of ventral lobe of gonocoxite (Fig. 14 ..... *gigas*
Gonostyli not reaching to tip of ventral lobe of gonocoxite (Fig. 15) 10

10 Blade of inner gonostylus with short dorso-distal spine and longer ventro-basal spine ..... *inelegans*
Blade of inner gonostylus with long dorso-basal spine and shorter ventro-distal spine ..... *marriwirra*

Molophilus (*Superbomolophilus*) *rowanorum* sp. n.

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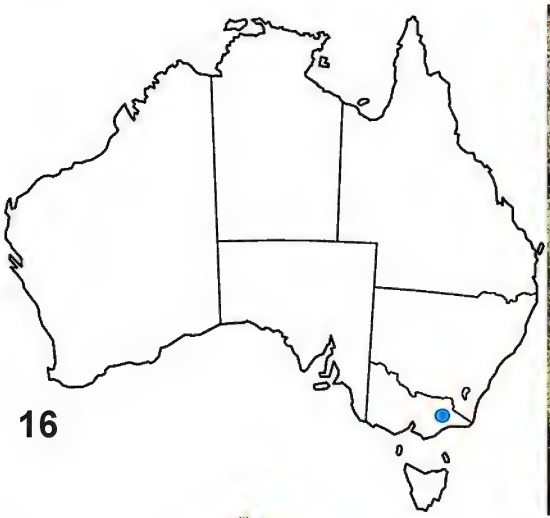
(Figs 16–24)

Type material. Holotype ♂, VICTORIA, Glen Valley, Glen Wills Creek off Kangaroo Creek Track (-36.867°S 147.478°E) (Figs 16, 17), 9 Nov 2019, Z. Billingham, NMV (T22484). *Paratype*: ♂, same data as holotype, GHD (T24772).

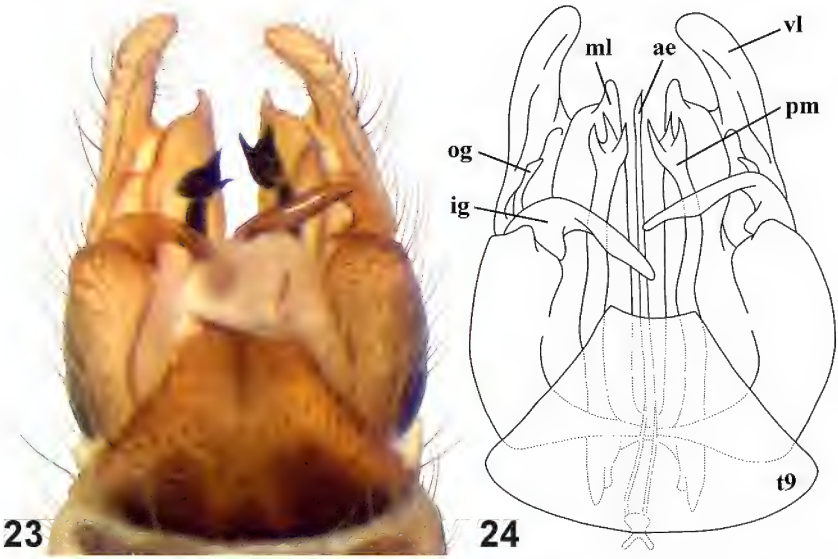
Description. Male (Fig. 18): body length (excluding antenna) 6.2 mm, wing length 7.0 mm. Head dark greyish brown, antenna and palpus deep brown. Antennal flagellomeres densely covered in short setae (Fig. 19). Antenna extending back to scutal lobes. Pronotum yellowish brown. Prescutum, scutum, mediotergite and scutellum dark brown, paler brown at the prescutal pit, centre of transverse suture, lateral angles of scutal lobes and anterolateral corners of scutellum (Fig. 20). Paratergite pale yellow to white, forming distinct pale stripe between terga and pleura. Pleura dark brown, membranous area around thoracic spiracle white (Fig. 21). Coxae, and trochanters golden brown. Basal 1/3 to 1/2 of femora golden brown, darkening to deep brown distally. Tibiae and tarsi dark brown to black. Wing (Fig. 22) pale grey, with dense microtrichia along veins and wing margins. Halter with stem pale grey and knob whitish. Abdomen dark brown. Hypopygium (Figs 23, 24) golden brown with base of tergite 9 and lateral margin of gonocoxite darker greyish brown. Tergite 9 elongate, trapezoidal, apical margin shallowly concave. Quadrate membranous structure, possibly proctiger, extending from below tergite 9, weak rectangular sclerite on each distolateral angle. Gonocoxite with large ventral lobe, curved slightly mediad and tapering to rounded apex. Medial lobe strongly developed, extending to



Figs 16–18. *Molophilus* (*Superbomolophilus*) *rowanorum* sp. n.: (16) known distribution; (17) type locality – Glen Wills Creek; (18) male habitus, lateral view.

about 2/3 length of ventral lobe, apex tapering to narrow finger-like projection. Dorsolateral lobe only minimally developed. Inner gonostylus bent medially at near right angle just beyond its base, continuing as large straight rod, tapering in distal 1/3 to blunt tip. Outer gonostylus weakly developed, not extending far beyond base of inner gonostylus, faintly curved, base narrow, distally somewhat

Figs 19–22. *Molophilus* (*Superbomolophilus*) *rowanorum* sp. n.: (19) head, lateral view; (20) thorax, dorsal view; (21) thorax, lateral view; (22) wing.



Figs 23, 24. *Molophilus* (*Superbomolophilus*) *rowanorum* sp. n.: (23) hypopygium ventral view; (24) hypopygium detail, proctiger excluded.

spatulate. Paramere greatly developed, subequal to length of medial lobe, narrow and lightly undulate along its length, expanded distally into trifid head, each tip sharply pointed. Aedeagus fairly straight, a little longer than parameres.

The paratype does not differ significantly from the holotype.

Female: unknown.

Etymology. This species is dedicated to the Rowan family, particularly Murielle Rowan, for all the support given to the first author.

Discussion. The strongly developed medial lobe of the gonocoxite readily distinguishes *M.* (*S.*) *rowanorum* sp. n. from all other species of *Superbomolophilus*. In having the inner gonostylus strongly bent near the base and the parameres greatly developed and elongate, *M.* (*S.*) *rowanorum* is similar to *M.* (*S.*) *froggatti* and *M.* (*S.*) *barringtonensis*, perhaps indicating a close relationship with these two species.

Acknowledgements

The map provided in Fig. 16 was modified from wikipedia (*https://commons.wikimedia. org/wiki/File:Australia_states_blank.png*) under a creative commons license. Dr. Peter Lind (GHD) is thanked for his help and patience in the field, and ongoing support of the first author's studies. John Martin (Australian Museum) is thanked for photographing the hypopygia of *Molophilus* (*Superbomolophilus*) *froggatti*.

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THE DISTRIBUTION AND CONSERVATION STATUS OF THE SHORTER RAINFOREST GROUND-BEETLE, *NURUS BREVIS* MOTSCHULSKY, 1865 (COLEOPTERA: CARABIDAE), IN NORTH-EAST NEW SOUTH WALES

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Abstract

Surveys for the Shorter Rainforest Ground-beetle, *Nurus brevis* Motschulsky (listed as endangered in New South Wales), were undertaken in rainforest habitat in the Lismore–Richmond Range region in north-east New South Wales. Four new populations were found, taking the number of extant populations from five to nine and extending the northern, southern and western range limits. The Richmond Range is central to the conservation of the species, containing most of the total population of the ground-beetle, as well as most of the potential habitat. The surveys located 979 active burrows along the range in five populations from Pademelon Road (Richmond Range National Park) in the north to Pennefathers Road (Cherry Tree State Forest) in the south. *Nurus brevis* has a highly disjunct distribution, with the four other known populations approximately 50 km east of the Richmond Range in the Lismore–Bungabee area. These four populations are relatively small and disjunct. A range of potential threats were identified, including over-abundant Australian Brush-turkeys, weed invasion, Cane Toads, stormwater run-off and flying-fox camps. Eight of the nine known *N. brevis* populations are in reserves and the single population on private property is managed for conservation by the current landowner. *Nurus brevis* appears to be relatively secure in the Richmond Range, however management intervention may be required to maintain the eastern populations.

Keywords: Carabid conservation, threatened invertebrates, rainforest insects

Introduction

Nurus brevis Motschulsky, 1865 (Fig. 1) is a large flightless carabid beetle (Will and Monteith 2018). It is restricted to rainforest in north-east New South Wales (NSW) where, like its close relative *N. atlas* (Laporte, 1867) (Charley and Andren 2018), it constructs burrows under the downslope side of rocks, exposed roots and logs. The characteristic location, size and maintenance of a distinctive 'stage' at the entrance enable the burrows to be efficiently identified (Fig. 2). Surveys can therefore be carried out rapidly and visually, without the need to excavate or trap the animals.

The earliest known specimens of *N. brevis* are undated and from unspecified localities. Of those listed by Will and Monteith (2018) the earliest is the type material of *N. brevis* from 'Nouvelle Hollande' described by Motschulsky (1865), followed by types from 'Clarence River' of the synonymic species, *N. solandersii,* described by Laporte (1867). Will and Monteith (2018) also list unlabelled specimens in the Australian National Insect Collection from the French and Van de Poll collections of the late 1800s. It was not until 1972 that specimens from precise localities were collected when Geoff Monteith pitfall-trapped specimens in Rotary Park, Lismore (Will and Monteith 2018).

Monteith trapped *N. brevis* at two additional locations in 1977, in what are now national parks: Mallanganee National Park (NP) and Richmond Range NP (at

Cambridge Plateau). These locations are more than 50 km west of the original Rotary Park location and are highly likely to be disjunct, since there is now predominantly cleared land between them (Fig. 3). In 2001, *N. brevis* was known from only these three locations, resulting in the species being listed as endangered in NSW (Scientific Committee 2001).

In 2008, Monteith found *N. brevis* at Lismore in Wilson Nature Reserve (NR) and verified another occurrence on private property west of the town near Kyogle Road. These five locations were the only ones known for the species at the commencement of this study (Fig. 3). More recently (in 2016), he added to the knowledge of the Richmond Range distribution by finding an additional site on Cambridge Plateau and another in 2017 at Mallanganee.

Our objectives in this study were to (i) investigate the distribution of *N. brevis* by surveying known and potential habitat in rainforest remnants in the Lismore–Richmond Range region, (ii) confirm any new populations found by collecting specimens and lodging them with the Queensland Museum, (iii) map active burrows and use this map, along with rainforest mapping, to assess the approximate size of individual populations, and (iv) note the habitat condition and any threats for each population.

Study Area

The study area (Fig. 4) was constrained by three geographic variables:

1. The distribution of known *N. brevis* sites, which focussed the study area on the Lismore–Richmond Range region.
2. The distribution of rainforest (the only habitat known to be occupied by *N. brevis*). The Richmond Range contains most of the rainforest in the study area. Rainforest is scarce across the broad Richmond River valley that bisects the study area north to south (some small fragments remain on otherwise cleared flood plain) and is also generally very scarce in the south of the region.
3. The distribution of other *Nurus* species. We assumed that *N. brevis* did not overlap with other *Nurus* species. There is good support for this assumption with respect to *N. atlas* in the east from the extensive early surveys of Monteith and later Charley (2018) in the Lismore area (Charley and Andren 2018), where no overlap has been found. *N. latipennis* occurs to the north (Nightcap Range and Border Ranges) and west (Yabbra, Tooloom and Koreelah) of known *N. brevis* sites (Will and Monteith 2018). There is less support for assuming that there is no overlap in these areas, as fewer surveys have been carried out, and it was beyond the scope of the current study to survey such an extensive region.

Methods

The surveys were conducted in known and potential *N. brevis* rainforest habitat. Since most rainforest in the study area is on public land, most of the sites were

Figs 1, 2. *Nurus brevis*: (1) adult from Cambridge Plateau, Richmond Range NP; (2) burrow downslope of a fallen branch at same locality, with distinctive cleared 'stage' in front of entrance.

Fig. 3. The five *Nurus brevis* populations identified prior to this study, broadly defined by the records (yellow triangles) listed in Will and Monteith (2018).

also located on public land. Surveys were conducted at 15 locations (Fig. 4), with 32 individual surveys carried out over 19 days between 1 April 2019 and 17 July 2019 (Charley 2019).

Meandering searches (randomly sampling the search area) and grid searches (systematically covering the whole search area) were conducted in areas of potential habitat for the characteristic burrows that are found under the downslope side of rocks, logs and exposed roots. Searches were initially carried out in known or historical locations, then in areas with no previous survey history. The location

of each burrow and details of the substrate and shelter type were recorded, along with a brief habitat assessment. Most of the surveys were conducted by the same observer (DC), resulting in a consistent dataset (Charley 2019).

Where possible, all suitable potential habitat was searched. However, finding new occurrences was a higher priority than comprehensively surveying a single location. With limited resources available, searches were therefore often restricted to a portion of the total rainforest habitat. The focus was on delineating the extent of the population by surveying the margins of the contiguous habitat patches.

Results

A total of 1,358 burrows were recorded at 10 of the 15 general survey locations (Fig. 5 and Appendix 1). We consider that this is likely to represent nine separate populations due to the barriers that occur between them:

- The four Lismore–Bungabee occurrences are separated from the five on the Richmond Range by 35.8 km of predominantly cleared rural land.
- The four eastern occurrences are individually separated by rural and/or urban land, with minimum separation distances of 11.0, 9.7 and 2.3 km (through urban Lismore).
- The Richmond Range occurrences are separated, from north to south, by 2.1, 12.7, 9.6 and 3.2 km. All gaps include unsuitable habitat of drier sclerophyll forest and the northern three occurrences are separated from the southern two by cleared rural land and the Bruxner Highway.

There is no data on the dispersal capacity of *N. brevis* and minor infrequent interaction between some of the Richmond Range occurrences cannot be completely excluded. However, we consider it highly likely that there would be no interaction between the nine occurrences and that, for conservation purposes, they should be considered as nine separate, self-sustaining populations.

Four of the six locations where burrows were not recorded were beyond the currently known range: to the west (Pretty Gully Flora Reserve), south (Mount Pikapene NP) and north (Bungdoozle and Peter Finn Conservation Area). Areas east of the currently known range had already been well surveyed, for *N. atlas* (Charley and Andren 2018). Therefore, within the currently known range of the species, 9 of the 11 areas surveyed were occupied by the ground-beetle. Examples of the survey techniques are illustrated in Figs 6 and 7.

To determine the extent of the population on the Cambridge Plateau, a 6 km linear search (Fig. 7) was conducted throughout the rainforest vegetation of the plateau. We consider that it effectively surveyed approximately 2 m each side of the survey track, an area of 2.4 ha. Within this area, 792 burrows were found (i.e. 330 burrows/ha). Therefore, across the entire plateau, there may be several hundred thousand *N. brevis* burrows.

Fig. 4. The *Nurus brevis* study area, approximately delineated by the 15 survey sites mapped and listed below. Blue represents the distribution of rainforest, while records of *N. atlas* are shown as black triangles and *N. latipennis* as red (from NSW BioNet and Will and Monteith 2018). The survey sites are: (1) Rotary Park, (2) Wilson NR, (3) Mallanganee NP, (4) Richmond Range NP (Cambridge Plateau), (5) Richmond Range NP (Link Fire Trail), (6) Richmond Range NP (Theresa Creek Fire Trail), (7) Richmond Range NP (Gorge Creek Fire Trail), (8) Richmond Range NP (Pademelon Road), (9) Richmond Range NP (Bungdoozle), (10) Richmond Range State Forest (Mount Brown), (11) Mount Pikapene NP, (12) Bungabee NR, (13) Cherry Tree State Forest (Pennefathers Road), (14) Pretty Gully Flora Reserve, (15) Peter Finn Conservation Area.

The six specimens that were collected (Appendix 1) and lodged with the Queensland Museum were all identified by Geoff Monteith as *N. brevis*.

Discussion

Nurus brevis occurs in two discrete regions: the Richmond Range in the west and Lismore–Bungabee in the east. Genetic samples from these two regions were included in a recent analysis (Will and Monteith 2018) where they were classified as *N. brevis*, which is compatible with morphological observations (G. Monteith, *pers. comm.*).

North of the known *N. brevis* distribution, in the Nightcap and Border Ranges, we currently assume that *N. latipennis* is present and *N. brevis* is absent (Fig. 4). Co-occurrence is exceptional in the distributions of the eight *Nurus* species and the more usual pattern is complete segregation (Will and Monteith 2018). However, general co-occurrence is known in some instances, with the separation

of species occurring at a fine scale, instead of a landscape scale. This is seen in the adjacent distributions of *Nurus perater* (Sloane, 1923) and *Nurus moorei* Will and Monteith, 2018 at both Numinbah Arch and Upper Tallebudgera in southern Queensland (Will and Monteith 2018). Further survey is warranted to confirm the extent of the *N. brevis* distribution in these northern areas. For example, while the range of *N. brevis* was extended in this study by 15 km north along the Richmond Range (to Pademelon Road in Richmond Range NP), further north, Bungdoozle was partly surveyed without finding any *Nurus* species. Additional survey is required in this area, as well as in Toonumbar NP (e.g. Murray Scrub and Eden Creek).

Three new populations of *N. brevis* were located on the Richmond Range, reflecting the concentration of suitable habitat along the range. On the Cambridge Plateau, there is a very large and widespread population, which could number in the hundreds of thousands. This population currently appears to be secure and likely to persist in the medium term without targeted conservation management, although it could benefit from general weed and feral animal control, and protection from intense wildfire.

The Bonalbo valley west of the Richmond Range separates the Richmond Range rainforests from those of Yabbra. *Nurus latipennis* has been recorded in Yabbra NP (Fig. 3), which may be an indication that *N. brevis* does not occur that far west. One survey was conducted at Pretty Gully, south of Yabbra NP, without locating any *Nurus* species.

At Mallanganee NP, there are stormwater issues where *N. brevis* occurs immediately downslope of the Bruxner Highway and several drains discharge into the occupied habitat. The southern limit of the species was extended south of Mallanganee by 5 km to Pennefathers Road (Cherry Tree State Forest), where burrows were associated with deeper soils adjacent to an ephemeral waterbody. *Nurus* species were not located further south in Mount Pikapene NP, although more extensive surveys could be conducted that focus on areas of higher potential soil moisture, such as near riparian flats or water bodies. Apart from the Mount Pikapene area, there is relatively little suitable rainforest habitat in the south of the region, across the relatively dry expanse of the Richmond River valley. If *N. brevis* does occur in this area, it is likely to be in small and isolated populations.

East of the species' range, considerable survey effort has failed to detect the co-occurrence of *N. brevis* and *N. atlas*, despite the distance between the two species being only 9 km. The opportunities for finding significant populations of *N. brevis* beyond its eastern extent in Lismore at Rotary Park appear to be limited.

The eastern (Lismore–Bungabee) populations of *N. brevis* are relatively small and disjunct. They are likely to be less resilient to the droughts that are predicted to intensify under climate change and the matrix between occupied habitats is comprised mostly of urban or medium-density rural land that is likely to be

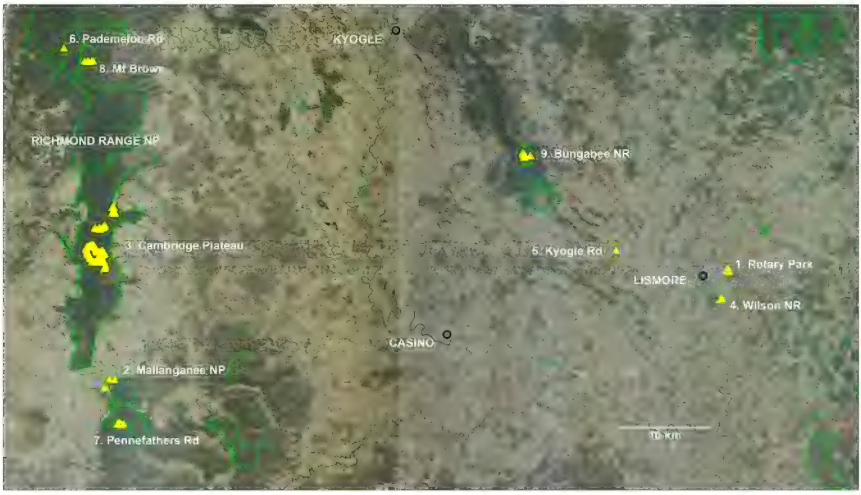


Fig. 5. The nine extant populations of *Nurus brevis* known following this survey, broadly delineated by records (yellow triangles) from the NSW BioNet and Will and Monteith (2018).

uninhabitable to a flightless ground-beetle. One of the key eastern populations is at Bungabee NP, located within a comparatively large remnant and reserved for conservation. Further survey is recommended to determine the size of the population.

Rotary Park and Wilson NR were comprehensively surveyed and significant burrow counts were recorded; 179 at Rotary Park and 99 at Wilson NR. At Rotary Park the presence of a large Flying-fox (*Pteropus* spp.) colony, Ibis (*Threskiornis* spp.) nest and roost sites, extensive disturbance caused by numerous Australian Brush-turkeys *Alectura lathami* Gray, stormwater drains, severe weed infestations and the presence of Cane Toads *Rhinella marina* Linnaeus within the remnant (DC, *pers. obs.*) are likely to be having an impact on this isolated and threatened population.

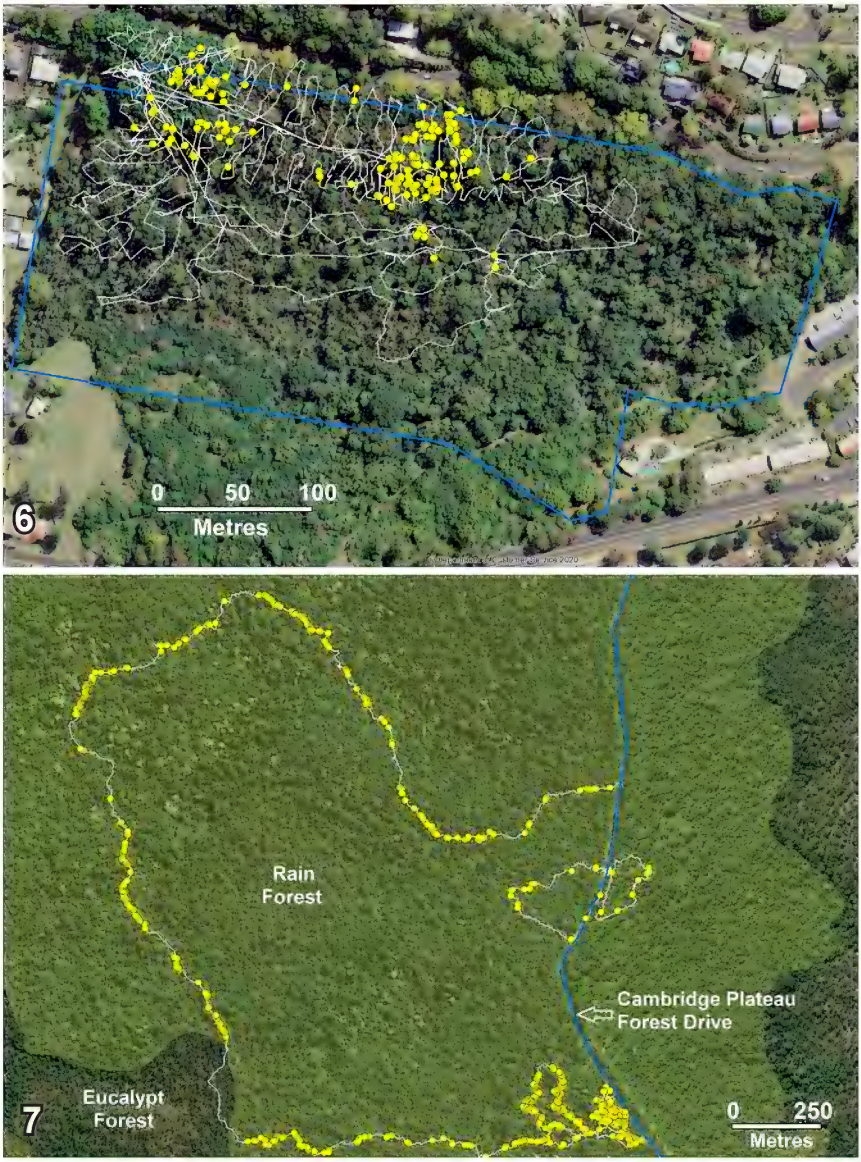
The Wilson NR population is small and confined to the deeper soils in the south-eastern section of the reserve. The remainder of the reserve is steep and very rocky and appears to be unsuitable. Weeds are a significant problem in Wilson NR and Rotary Park, including Small-leaved Privet *Ligustrum sinense* (Lour.), Camphor Laurel *Cinnamomum camphora* (L.) J. Prestl. and Cat's Claw Creeper *Dolichandra unguis-cati* (L.) L.G. Lohmann. At both sites, burrows were rare or absent where these weeds dominated. Targeted weed control programs would help secure these populations. On the eastern edge of Wilson NR, it would be possible to expand the habitat by rehabilitating the adjacent cleared, grassed area. Ground-beetles are known to be able to colonise regenerating rainforest, with *N. atlas* occupying the planted rainforest habitat at Wollongbar Agricultural Research Station (Charley 2018).

Although *N. brevis* occurs in sites with emergent eucalypts, all locations supported a rainforest mid-storey. The rainforest habitats occupied are diverse, highlighted by the occurrence of *N. brevis* in the dry rainforests at Mallanganee NP, which contrasts with the wet rainforests of Richmond Range NP. However, the extent of rainforest habitat was difficult to estimate in places due to apparent errors in the vegetation mapping (Office of Environment and Heritage 2010), with some drier eucalypt forest mapped as rainforest and areas of rainforest omitted. This appeared to occur at Bungdoozle (Richmond Range NP), Bungabee NR, Mallanganee NP, Cherry Tree State Forest and on private property west of Lismore. Further refinement of the distribution, abundance and management of *N. brevis* will require improved and more detailed rainforest mapping.

All but one of the known *N. brevis* populations are protected on public tenure: three populations in Richmond Range NP, one each in Mallanganee NR, Wilson NR and Bungabee NR, two in protected rainforest on State Forest (Richmond Range State Forest and Cherry Tree State Forest), and one managed by Lismore City Council (Rotary Park). The other population is on private property at Kyogle Rd near Lismore and is managed for conservation by the current landowner.

There has been a dramatic historical decline in forest cover across the study area and much of the remaining remnant forest is disturbed regrowth. Faunal differences between regrowth and old growth forests are usually referenced to vertebrate fauna, such as tree hollow-dependent species, while differences in invertebrate communities (Toft *et al.* 2019, McGee *et al.* 2020) are often overlooked. *N. brevis* requires an open understorey and is unlikely to be capable of tolerating excessive ground-level disturbance. This may be direct disturbance or caused by canopy openings that result in abundant growth of ground-cover plants and may lead to the domination of the understorey by weed species (such as introduced grasses or Camphor Laurel), creating unsuitable habitat conditions for the ground-beetles. A poor ability to re-colonise habitat is likely to result in *N. brevis* remaining absent from disturbed remnants for a long period of time (dispersal of more than a few hundred metres has been observed to be exceptional in flightless carabids (den Boer 1990)). The presence of *N. brevis* in a remnant is therefore likely to indicate a less intense history of disturbance. This is supported by *N. brevis* being abundant in the least disturbed areas (such as Cambridge Plateau) and absent or patchy in remnants with a greater disturbance history (such as Rotary Park).

Due to the sensitivity of many carabids to human-induced environmental change, including fragmentation, timber harvesting and grazing, they have been widely used as bioindicators (Raino and Niemela 2003). *Nurus brevis* may be a useful indicator for monitoring environmental change along the Richmond Range. Furthermore, where they occur in large numbers, ground-beetles may contribute to soil quality through fine scale bioturbation (Menta and Remelli 2020) and influence the structure of the leaf litter invertebrate community through predation.



Figs 6, 7. Two examples of the 2019 *Nurus brevis* surveys, with the GPS walking tracks shown as grey lines and burrow locations as yellow dots. **6.** Rotary Park, Lismore, surveyed in a grid search pattern. **7.** Cambridge Plateau, Richmond Range NP, surveyed in a meandering search pattern (some grid pattern in the bottom right corner) and illustrating the distribution of burrows across the plateau and the absence of burrows in eucalypt forest (Charley 2019).

The decline of carabid diversity has been documented in habitat remnants within developed landscapes overseas (Homburg *et al.* 2019). For *N. brevis*, decline is most likely in the small and isolated eastern populations around Lismore, such as Rotary Park and Wilson NR, that have multiple management issues. In these predominantly cleared landscapes, species that depend on forests for at least part of their life cycle are forced to utilise small and isolated remnants of native vegetation. These remnants can be adversely impacted by the high numbers of native species present (e.g. Brush-turkeys and Flying-foxes), as well as feral species (e.g. Red Foxes and Cane Toads). Remnants may become ecologically unsuitable for native species that are unable to adapt to the new conditions; ground-beetles may struggle to survive in the longer term. We believe, however, that *N. brevis* is a historically significant species in the region and therefore these Lismore reserves should be managed to maintain the ground-beetle's presence.

Acknowledgements

We especially thank Geoff Monteith for his ongoing invaluable advice and crucial information on historical locations of *N. brevis*. Don Durrant, the owner of Peter Finn Conservation Area, provided access and field assistance at that location and Stephen King, National Parks and Wildlife Service (NPWS) Kyogle assisted with field surveys at Mallanganee NP. Allan Goodwin, also of NPWS, is thanked for his enthusiastic support and Chris Reid, Kipling Will and Geoff Monteith for valuable comments on a draft manuscript. Surveys and specimen collections were conducted under NSW Scientific Licences SL100810 and SL100122. The project was funded by the NSW Saving our Species program.

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Appendix 1. *Nurus brevis* burrow counts at each site and notes on habitat quality and management issues. *Area refers to the area of mapped rainforest.

Location	Area (ha)*	No.	Rapid Assessment
1. Rotary Park	8.8	179	High quality habitat confined to the northern slope against Uralba Road. Burrow sites under exposed roots and surface rock. Chocolate soils with black earths on lower slopes. Large areas steep and very rocky. Sheet erosion and nutrient input from stormwater and road drains. Severe weed infestations throughout, including Privet, Camphor Laurel, Cat's Claw. Numerous Brush-turkey nests. Cane Toads. Some potential for visitor disturbance and collectors. Burrows mostly absent from disturbed forest areas dominated by Camphor Laurel, Small-leaved privet and other weeds.
2. Wilson NR	22	99	High quality habitat confined to the east and southeast. Burrow sites under exposed roots and surface rock. Chocolate soils with black earths on lower slopes. Large areas are steep and very rocky. Severe weed infestations (including privet, Camphor Laurel, Cat's Claw) throughout. Possible increasing number of Brush-turkeys, Cane Toads. Potential for visitor disturbance and collectors. Burrows mostly absent from disturbed forest areas dominated by Camphor Laurel, Small-leaved Privet and other weeds.
3a. Mallanganee NP (Bruxner Hwy edge)	369	3	Moderate quality site—relatively dry and steep site on chocolate soils. Burrow sites mostly under exposed roots. Several managements issues, including stormwater drainage from the highway and weed infestations. Partial search only.
3b. Mallanganee NP (Hogarth Range Rd)	Incl. in above	11	Several minor managements issues, including weed infestations and potential for disturbance and drying due to proximity to forest edge. Burrow sites mostly under exposed roots. Chocolate soils. Partial search only. Appear to be absent from steep slopes.
3c. Mallanganee NP (Pennefathers Rd)	<13	0	Moderate quality habitat, rocky in parts. Chocolate soils. Partial search only.
4. Richmond Range NP (Cambridge Plateau)	1,353	792	One specimen taken. Very extensive high-quality habitat on red krasnozems. Management issues minor. Partial search only, but clearly a very large population. Mostly absent from eucalypt forest.
5–6. Richmond Range NP (Cambridge Plateau north)	348	57	Very extensive high-quality habitat on red krasnozems. Burrows under exposed roots. Management issues minor. Partial search only, but clearly part of a very extensive population.
7. Richmond Range NP (Gorge Creek)	1,603	0	Extensive habitat on red krasnozems. Some parts steep and rocky. Management issues minor, although some potential for fire to penetrate drier parts of the site, including rainforest. Extensive areas of very dense Lantana surround the southern and eastern boundaries of the rainforest. Partial search only—further survey required.

Appendix 1 (cont.). *Nurus brevis* burrow counts at each site and notes on habitat quality and management issues. *Area refers to the area of mapped rainforest.

8. Richmond Range NP (Pademelon Rd)	48	5	One specimen taken. Extensive habitat on chocolate soils. Burrows under exposed roots. Some parts steep and very rocky. Management issues minor (some potential for fire to penetrate the drier parts of the site). Partial search only.
9. Richmond Range NP (Bungdoozle)	364	0	Very extensive high-quality habitat on red krasnozem soils. Management issues minor. Numerous Australian Brush-turkey nests. Partial search only. Areas accessed mostly steep and flats mostly with a relatively deep leaf litter cover.
10. Richmond Range NP (Mount Brown)	66	58	One specimen taken. Extensive habitat on red krasnozem soils. Burrows under exposed roots. Some parts steep and very rocky. Management issues—potential for wildfire to penetrate rainforest. Extensive areas of very dense Lantana surround the southern and eastern boundaries of the rainforest. Numerous Australian Brush-turkey nests. Partial search only.
11. Mount Pikapene NP	1,764	0	Forest type very dry, steep in parts. Chocolate soils and sandy clay loams. Increasing weeds with Cat's Claw Vine throughout forest. Limited riparian flats or sites with year-round higher soil moisture. Partial search only.
12a. Bungabee NR (Oaky Ck—west)	~62	56	One specimen taken. Burrow sites under exposed roots on riparian flats above flood levels or on adjacent lower slopes. Chocolate soils, some red krasnozems. Rainforest mapping inaccurate. Areas of very dense Lawyer Vine thickets. Weeds. Numerous Australian Brush-turkey nests. Potential for fire to penetrate narrow riparian strips. Access limited by Lawyer Vine.
12b. Bungabee NR (Oaky Ck—east)	~24	45	One specimen taken. Burrow sites under exposed roots on riparian flats above flood levels or on adjacent lower slopes. Chocolate soils. Rainforest mapping inaccurate. Areas of very dense Lawyer Vine thickets. Weeds. Numerous Australian Brush-turkey nests. Potential for fire to penetrate narrow riparian strips. Access limited by Lawyer Vine.
13. Cherry Tree SF (south of Pennefathers Rd)	36	53	One specimen taken. High quality, relatively weed free. Weeds around margins of forest. Chocolate soils and sandy clay loams. Burrow sites under exposed roots. Burrows mostly associated with deeper soils with higher soil moisture and mostly adjacent to a shallow seasonal lagoon.
14. Pretty Gully Flora Reserve	29	0	Crown reserve managed by local community. Steep in parts. Red krasnozems. Some potential in NW, minor weed infestations. Partial search only.
15. Peter Finn Conservation Area (Afterlee)	130	0	Extensive habitat on chocolate soils and sandy loams, some steep and rocky areas. Drainage lines mostly steep with limited area of riparian flats. Very minor weed infestations. Numerous Australian Brush-turkey nests. Under permanent conservation covenant.

NOTES ON THE BIOLOGY AND LIFE HISTORY OF *TAENARIS ARTEMIS JAMESI* BUTLER, 1877 (LEPIDOPTERA: NYMPHALIDAE: SATYRINAE) FROM TORRES STRAIT, QUEENSLAND WITH DISCUSSION OF VARIATION IN WING PATTERN CHARACTERS OF REARED PROGENY

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Abstract

Notes on the biology and life history of *Taenaris artemis jamesi* Butler from Dauan Island, Torres Strait, Queensland are presented, including colour illustrations of the full life history. Wing pattern variability in the progeny of two females is discussed and it is suggested that *Taenaris artemis staudingeri* Honrath is perhaps a junior synonym of *T. a. jamesi.*

Keywords: Owl butterflies, banana hostplant, *T. a. staudingeri*, *T. myops,* urticating larvae, variation in wing pattern characters.

Introduction

The genus *Taenaris* Hübner, [1819] is a group of large showy butterflies known as Owls (Brooks 1950). There are 25 known species, with the bulk of these confined to New Guinea and its outer islands, i.e. east of Weber's Line (Parsons 1998). Only two species occur outside of this New Guinea region, one being west of Weber's Line in the Sundaland region, *T. horsfieldii* (Swainson, [1820]) (Corbet and Pendlebury 1992), and the other occurring in the Bismarck and Solomon Archipelagos, *T. phorcas* (Westwood, 1858) (Parsons 1998; Tennent 2002). To the south of New Guinea three species are known from Torres Strait, Queensland (Lambkin 2010; Braby 2016), with one of these extending to mainland Queensland (Johnson and Johnson 1991).

In Torres Strait, the three species are confined to the far northern and eastern inhabited islands. *Taenaris artemis jamesi* Butler, 1877 is the most widely distributed and is recorded from all the northern islands, i.e., Saibai, Dauan and Boigu (Lambkin 2010; Lambkin 2021) and from all the eastern islands, Masig (=Stephen), Erub (=Darnley) and Mer (=Murray) (Lambkin 2010). Just a single female has been recorded from the mainland at Lockerbie Scrub, north of Bamaga, Queensland (Johnson and Johnson 1991). *Taenaris catops turdula* Fruhstorfer, 1914 is known from a handful of specimens from Erub, Saibai and Dauan Islands, while just four males of *T. myops kirschi* Staudinger, 1887 were recorded from Dauan Island in 2006 (Lambkin 2010). Lambkin (2010) discussed the genus in Torres Strait, including species' habits, sexual dimorphism, and the degree of variation observed in the wing pattern characters of the adults. In addition, Lambkin (2010) investigated reliable taxonomic separation of female specimens, particularly those of *T. artemis* (Snellen van Vollenhoven, 1860) and *T. myops* (C. and R. Felder, 1860) and concluded that, based on current known diagnoses, females of the two species could not be reliably identified.

The life histories of *Taenaris* in general are not well known. Of the 20 species recorded from Papua New Guinea just nine of these have published information on their immature stages (Szent-Ivany and Barrett 1956; Parsons 1984; Merrett 1996; Parsons 1998). At the time of Lambkin (2010), the only information available on the life histories of *Taenaris* in Australia was that of Johnson and Johnson (1991) who described the final instar larva and pupa of *T. a. jamesi* from a larva collected from *Pandanus* sp. S. Parkinson (Pandanaceae) on Mer Island. In New Guinea, the early stages of *T. a. staudingeri* Honrath, 1889, which occurs north of the Central Cordillera, have been described, including monochrome and colour images of several larval instars, and the pupa (Merrett 1996, Parsons 1998). Merrett (1996) specifically, provided very detailed descriptions of each of the five instars and the pupa of *T. a. staudingeri.*

Materials and methods

Three females of *T. a. jamesi* were collected on Dauan Island in early January 2010, and each was enclosed in a large plastic bag (40 x 60 cm) with several pieces of two putative hostplants, *viz. Pandanus* sp. and *Musa sapientum* L. (Musaceae) (banana) (Fig. 1), including a wad of moist cotton wool. The plastic bags were kept in a shade house for 5 d where they received only dappled light (Fig. 2). Leaves were checked daily for oviposition. Female butterflies that laid egg clusters were retained after the five-day period and the resulting two progeny groups from the two females were reared in separate large plastic containers, each 300 x 200 x 120 mm. A single layer of paper towelling was placed in the bottom of each container and was replaced daily, while the host plant was replaced every two days. Livestock was housed in a quarantine facility (at 25°C), which, at the time, was situated at the Alan Fletcher Research Station, Sherwood, Brisbane.

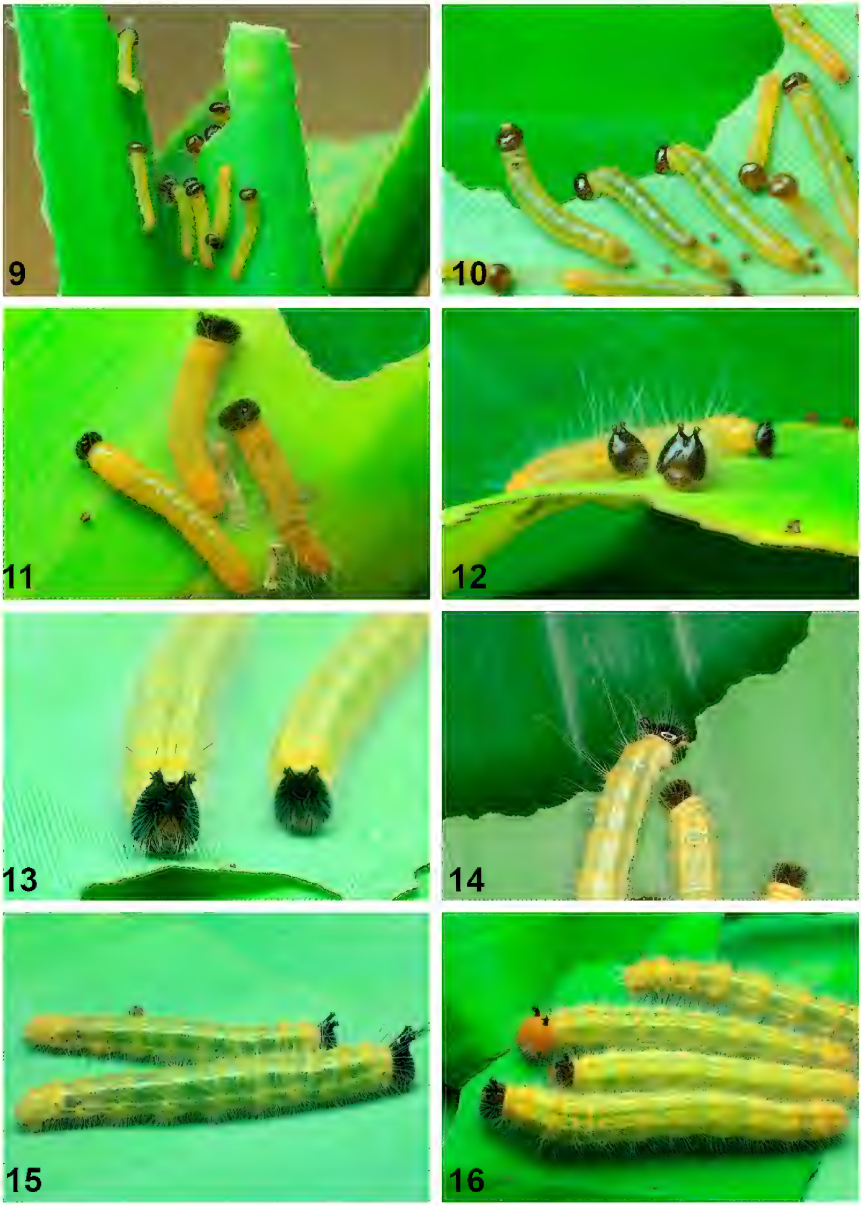
Additionally, the degree of wing pattern variation between adults reared from the two females (mothers) was recorded and this variation was compared to the wing pattern characters of the two females.

Results

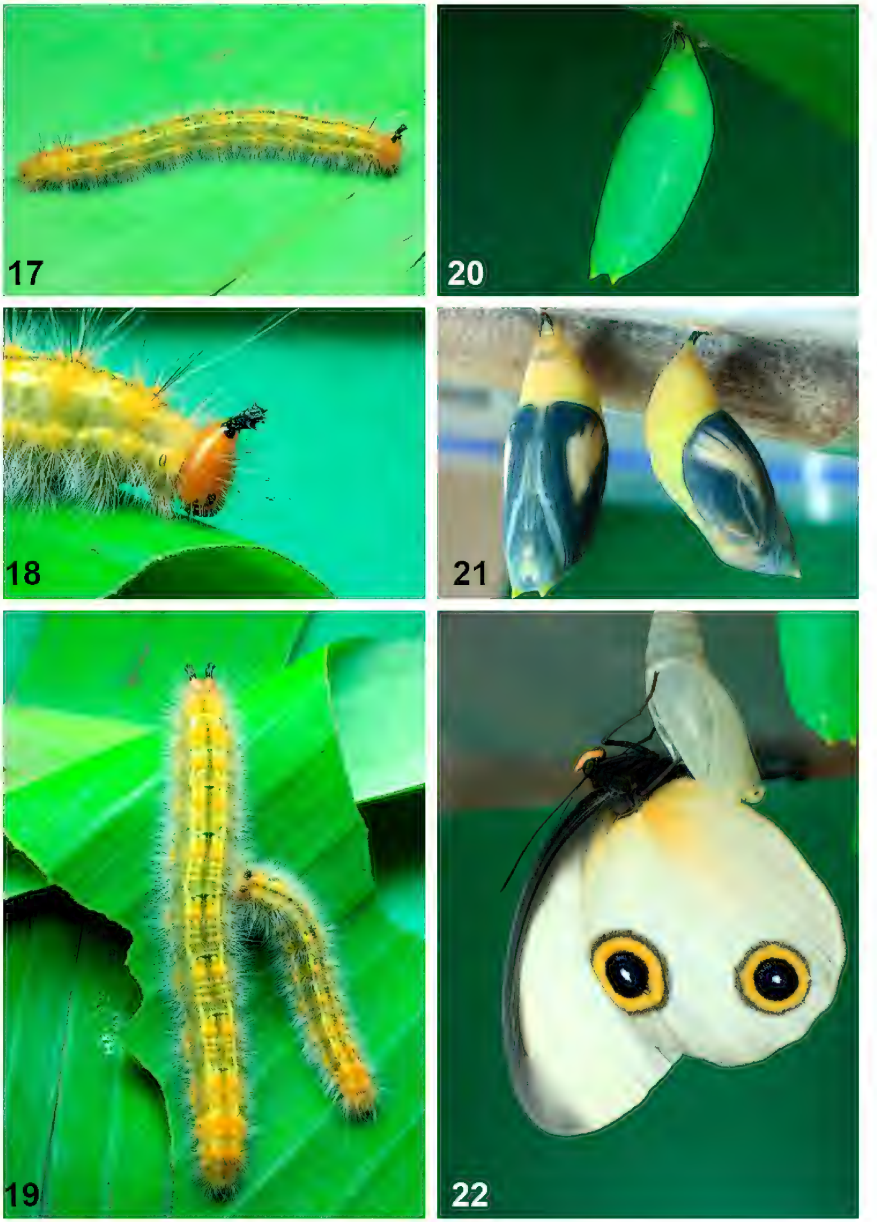
Biological and life history observations

Oviposition by enclosed female butterflies was not observed till day 5, on which two females (Numbers 1, 3) produced egg batches. The other female (Number 2) died at day 4. Females 1 and 3 each laid a single batch of eggs, 42 and 39 eggs, respectively on *Pandanus* leaves (Figs 3, 4). Oviposition occurred at dusk. Eggs were pearl white in colour immediately on oviposition and after 4 d turned pale pink (Fig. 5). At day 8 , the developing embryo could be seen through the chorion of the egg (Figs 6, 7) with eggs hatching at day 11. Larvae consumed the empty eggshells upon hatching (Fig. 8) and were gregarious up until and including the fourth instar (Figs 9–16), after which they were more solitary (Figs 17–19). Larval mortality during the first two instars was quite high on *Pandanus* so larvae were transferred to *M. sapientum*, after which there was little mortality (Fig. 10). When gregarious, larvae fed together and synchronously on the edges

Figs 1–8. *Taenaris artemis jamesi*: (1) female enclosed in plastic bag with two putative hostplants (*Pandanus* and banana); (2) shade house on Dauan Is. where female butterflies in plastic bags were held for 5 d. (3–8) Life history: (3) fresh egg batch of 42 (mother 1) (egg diameter 1.5 mm); (4) fresh egg batch of 39 (mother 3); (5) egg batch (mother 1) at day 4; (6, 7) egg batch (mother 1) at day 8; (8) larvae just after eclosion (4 mm).



Figs 9–16. *Taenaris artemis jamesi* life history: (9) 1st instar larvae (8 mm); (10) 2nd instar larvae (13 mm); (11–14) 3rd instar larvae (25 mm); (15) 4th instar larvae (45 mm); (16) 4th (43 mm) and 5th (65 mm) instar larvae.



Figs 17–19. *Taenaris artemis jamesi* life history: (17) 5th instar larva (67 mm); (18) 5th instar larval head capsule; (19) 5th instar larva (70 mm); (20) pupa (18 mm); (21) pupae prior to eclosion; (22) newly emerged adult female (as per Fig. 27).

of banana leaves (Figs 10, 14). Larvae also moulted and pupated synchronously, and adults eclosed synchronously (Figs 20–22). The bristles and hairs of the mature larvae were found to be urticating (Figs 17–19). The duration of the larval stage was approximately 40 d (n=34) with the pupal duration 15 d (n=34) and a total time of approximately 66 d from time of oviposition to time of adult eclosion. Overall, the five larval instars and pupa of the Dauan Island material matched the descriptions by Merrett (1996) of *T. a. staudingeri*, and the final instar larval description by Johnson and Johnson (1991).

Wing pattern characters of adult progeny

The wing pattern characters of the two females (mothers numbers 1, 3) were very similar (Figs 23, 24), i.e., upperside and underside: forewings white with dark grey apical (Fig. 23 A), costal (Fig. 23 B) and dorsal areas (Fig. 23 C); and hindwings white with grey apical (Fig. 23 D) and terminal areas (Fig. 23 E). Mother 3 had a more extensive upperside area of grey extending to tornus of the hindwing (Fig. 24). The upperside and underside subbasal areas of both mothers were yellow (Fig. 23 F). Three adults reared from each female were selected to illustrate the degree of variation between individuals (Mother 1: Figs 25, 27, 29, Mother 3: 26, 28, 30). Results indicated that the wing pattern characters of progeny from the same and similar looking females (mothers) of *T. a. jamesi* varied, both on their upper and undersides, i.e., in the extent and colour intensity of the apical, costal and dorsal areas of their forewings, and the apical and terminal areas of their hindwings. Some individuals had predominantly white underside hindwings (Figs 27, 29), with one female being almost totally white on the underside (Fig. 27). Of the 34 reared, apart from individuals with white undersides, wing pattern characters did not vary greatly with most specimens looking much like the two mothers. This contrasted with very dark and very pale wild caught specimens from Torres Strait as illustrated in Lambkin (2010).

Discussion

Accurate identification of the three male *Taenaris* species in Torres Strait is not difficult, specifically as the species have characteristic wing shapes and possess distinctive androconial scales or hairs (Lambkin 2010) on the uppersides of the wings. Distinguishing females of *T. artemis* and *T. myops* is far more problematic. Even the relatively modest degree of variation in wing pattern characters recorded in this study in females of *T. a. jamesi* reared from the same mother

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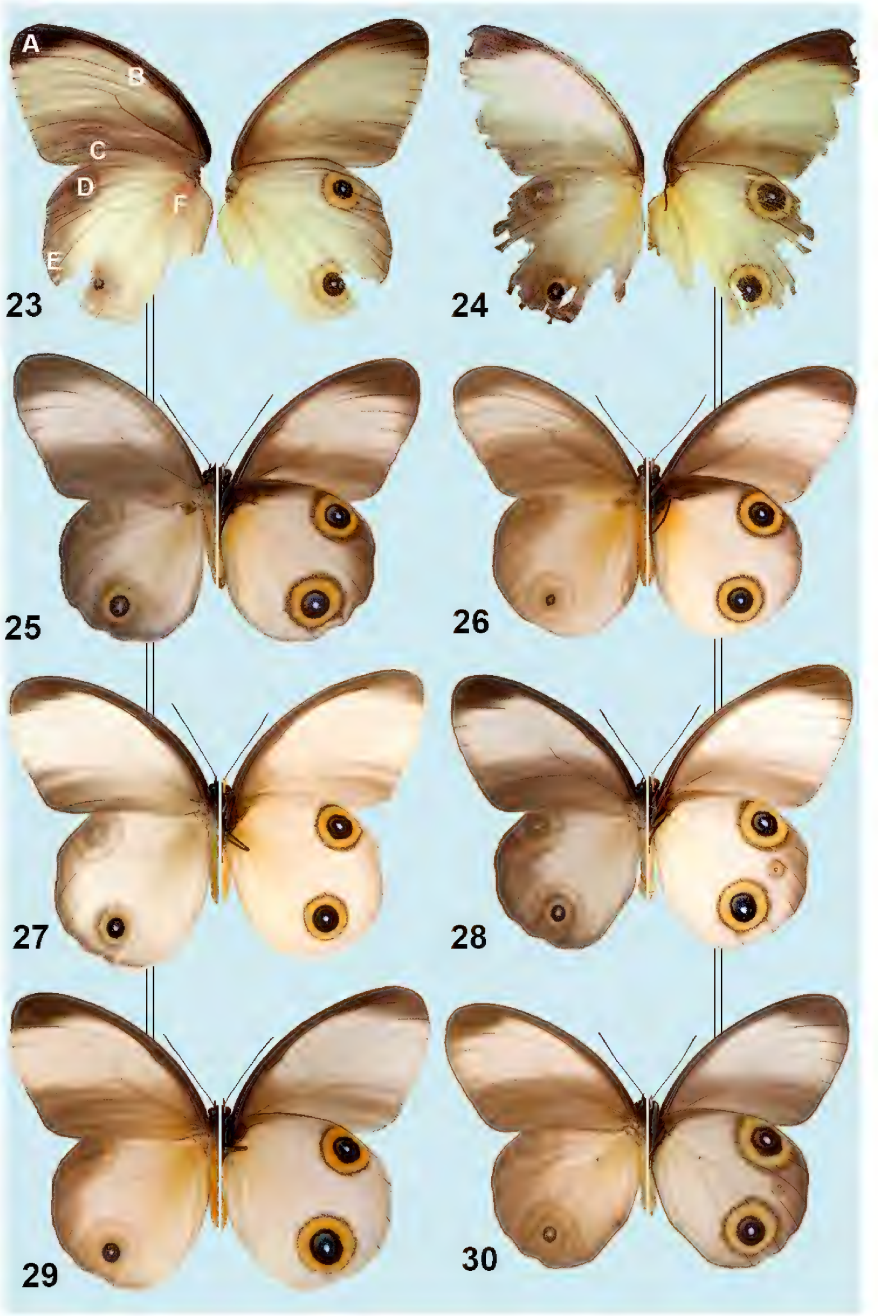
Figs 23–30. *Taenaris artemis jamesi.* All figures not to scale: upperside left, underside right [forewing lengths, in mm, in square brackets]. (23, 25, 27, 29) Mother No. 1 with representative progeny: (23) Mother No. 1, Dauan Is., Torres Strait, Qld, 5.i.2010 [51 mm]; (25) ♂, same data except em. 19.iii.2010 [47]; (27) ♀, same data except em. 13.iii.2010 [53]; (29) ♀, same data except em. 17.iii.2010 [56]; (24, 26, 28, 30) Mother No. 3 with representative progeny: (24) Mother No. 3, Dauan Is., Torres Strait, Qld, 5.i.2010 [52 mm]; (26) ♂, same data except em. 14.iii.2010 [46]; (28) ♀, same data except em. 12.iii.2010 [48]; (30) ♀, same data except em. 10.iii.2010 [48]. Letters A–F in white indicate features of wing areas discussed in text.


A
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or similar looking mothers still make it difficult to assign specific wing pattern characters to accurately discern females of *T. artemis* from *T. myops* based on our current knowledge of the degree of wing pattern variation for both species (Parsons 1998, Lambkin 2010). Males of both have been collected on Dauan Island (Lambkin 2010).

If the wing pattern characters of female *T. myops* are as variable as *T. artemis*, even from the same mother, then it is likely, based on current information, that the only certain way of identifying females of *T. myops* is to raise females from known larval stock. Final instar larvae of *T. myops* are distinctive in being dark wine-red in colour (Merrett 1996) compared to the green, yellow and orange coloured final instar larvae of *T. a. jamesi* (Figs 17–19).

Finally, the degree of variation in wing pattern characters recorded in this study for the progeny of *T. a. jamesi*, and the extreme variation in wild caught individuals as illustrated in Lambkin (2010), are likely indicative of the degree of variation also occurring in wing pattern characters of *T. a. staudingeri* as illustrated in Parsons (1998). Based on this evidence and identical larval morphology and colours of the two subspecies, it may be untenable to retain *T. a. staudingeri* as a valid subspecies of *T. artemis*, and thus, it is likely a junior synonym of *T. a. jamesi*. Until further collection material north of the Central Cordillera in New Guinea is examined, *T. a. staudingeri* is tentatively retained.

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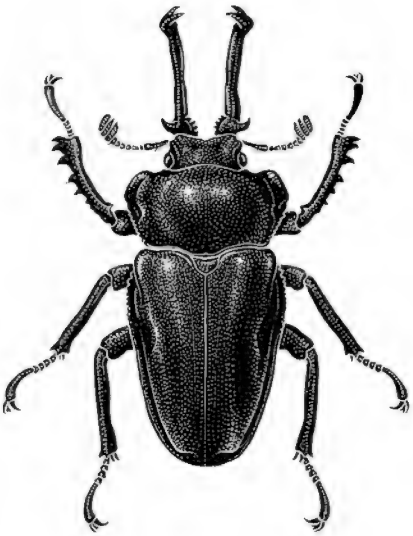

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